AD 268479

Price $2.25

Radiation-Processed Foods As A Component of the Armed Forces Feeding Systems

A GOVERNMENT RESEARCH REPORT

U. S. DEPARTMENT OF COMMERCE
Office of Technical Services

OPERATIONS DIVISION
Staff Paper ORO-SP-174
Published August 1961

Radiation-Processed Foods as a Component of the Armed Forces Feeding Systems

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Received for Publication
5 June 1961
Published
August 1961
by
The Johns Hopkins University
OPERATIONS RESEARCH OFFICE
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ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance received from Col L. M. Hursh, Office of The Surgeon General; Lt Col William B. Levin, Office of the Quartermaster General; Lt Col G. L. D'Amelio, US Continental Army Command; Lt Cdmr J. P. Tice, US Navy Supply Corps; Lt Col Roy E. Kyner, US Air Force Veterinary Corps; and Maj J. A. Todd, US Marine Corps, in providing specialized information pertinent to this study. Appreciation is extended also to the staff of the Quartermaster Food and Container Institute, and the Army Quartermaster Board for their contributions through discussions and the provision of research data. The authors also wish to thank Col E. M. Parker, Mr. R. A. Hafner, Dr. H. N. Hantzes, Mr. R. L. Hughes, and Lt Col C. E. Roberts of ORO, who reviewed the paper and gave helpful suggestions and criticisms.

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PROBLEM

To investigate the possible operational, logistical, and economic advantages to the armed forces of employing radiation-processed foods in the military feeding system and to provide a basis to assist the Army in making decisions on the irradiated-food research program.

FACTS

The preservation of food by sterilization with ionizing radiations is a relatively new concept and has not yet been attempted commercially. Experimentally many foods have been irradiated to determine the value, safety, and efficacy of such processing. Various radiation doses have been employed under different conditions of exposure and of associated treatment techniques. The ultimate goal is the attainment of a process that would safely and at reasonable cost preserve foods so that they could be stored in a fresh-like and wholesome condition for long periods of time without refrigeration.

For the armed forces, radiation-processed foods have been considered to have a great potential logistical and operational advantage over many foods now processed by other methods. Because meats are the highest-valued items in military rations, special research efforts have been placed on the development of radiation-processed meat items for ration components.

Considerable progress has been made since The Quartermaster General's (TQMG) extensive research program on irradiated foods began in 1953. However, plans for the construction and operation of a developmental pilot plant were indefinitely suspended on the recommendation of the Director of Research and Development of the Army in 1959. This action was taken partly because of the uncertainty of the wholesomeness of the foods, but mainly on the basis of need for adequate reliable information concerning the operational, logistical, and economic advantages that would justify the use of irradiated foods in military rations and the construction and operation of a pilot plant. In March 1960 a revised Army program on radiation preservation of foods was approved for wholesomeness studies and fundamental research toward development of end items.

A radiation-source facility containing a 1-million-curie Co^{60} source and a linear accelerator variable up to 24 mev is to be installed at Natick, Mass., in 1962 to aid developmental research on irradiated foods.

SUMMARY

DISCUSSION

Foods can be processed by gamma radiation from Co^{60} or by electron accelerators below energy levels of 10 mev without inducing measurable radioactivity in the foods. In order to be approved by the Food and Drug Administration, irradiated foods must not show radioactivity levels that are distinguishable from background. Sterilization processing of meats requires an exposure dose of 4.5 megarads (Mrad) preceded by heating to an internal temperature of about 160°F. Beef and pork processed in this way have remained acceptable for at least 25 months at 70°F storage temperature and for 16 months at 100°F. Bacon and ham have been stored about 1 year and chicken for about 1½ years with good acceptability. Flexible packaging is desired, but materials developed to date are not completely satisfactory to meet all military requirements.

Numerous extensive studies have been conducted to determine the wholesomeness of irradiated foods. Although analyses of the results of long-term animal feeding tests show no harmful effects attributable to radiation processing beyond correctable vitamin loss, prudently cautious recommendations by The Surgeon General (TSG) include about 3 years more of research for completion of the wholesomeness study program.

The present feeding system for a field army in a theater of operations involves the use of (a) bulk B rations prepared and served by organic mess personnel to most troops as far forward as the tactical situation permits; (b) canned 5-in-1 rations to feed small groups whose mission or tactical situation prevents their return to their parent unit for messing; and (c) canned C rations for individuals separated from group feeding by their tactical situation.

This study shows that logistical and operational advantages would be gained in the 1965–1975 time frame by using a unitized meal system and changing the feeding concept to eliminate field kitchens and food service personnel in units requiring high mobility and dispersion of troops. If irradiated foods are available they could provide the best major component of meals for use under most combat situations; if freeze-dehydrated foods are also available the latter could provide the easiest means for small groups of men to prepare a quick-serve meal. Irradiated foods have an advantage over freeze-dehydrated foods in that the latter would not be operationally suitable for the requirements of an individual ready-to-eat combat meal. The use of unitized ready-to-eat meals containing irradiated foods would be of considerable tactical advantage in the 1965–1975 time frame to ground forces in combat situations requiring high mobility and dispersion of troops. The ready-to-eat individual combat meal, with irradiated food components in a flexible package, is urgently needed for the best ration support of airborne, infantry, STRAC, and Marine Corps units in close contact with the enemy in situations that do not permit group feeding. For similar situations and for assault phases where resupply cannot be effected for several days, an individual combat food packet such as a lightweight high-caloric-content compressed-food item is urgently required.

For less active situations where small-group feeding is possible, 25- and 6-man quick-serve meals containing freeze-dehydrated foods could be used. Uncooked irradiated and uncooked dehydrated foods could be used for meals prepared by food service personnel for larger group feeding during static situations in rear areas. Foods processed by these two methods would offer approximately equal logistical advantage over canned B rations or A rations. Except when Navy and Air Force personnel might be deployed as ground-force units, they have little tactical requirement for either irradiated foods or freeze-dehydrated foods.

There is a continuing requirement for improved logistical operations to support the high mobility expected of US forces in the 1965–1975 time frame. The use of irradiated foods as the major component of rations in a theater of operations during combat would allow net fuel savings of over 96,000 tons/year per 2 million men by eliminating field kitchens, bakery companies, and refrigerant compressors. Exclusive use of dehydrated foods in rations would allow slightly smaller fuel savings of about 91,000 tons/year per 2 million men. When the fuel requirements of the light-truck companies needed to supply bulk fuel to kitchens, etc., are added to the other savings for irradiated food, the total savings in fuel equals about 99,000 tons/year per 2 million men, or the equivalent of 4.8 tanker trips.

The dollar savings from logistical advantages of using only rations containing irradiated components (instead of thermally processed rations) in a theater of operations for 1 year is estimated to be $412 million per 2 million men or 56 cents/man/day.

Climate, terrain, and guerrilla activities are shown to influence logistical operations in limited wars, making advantageous at times the use of irradiated foods instead of freeze-dehydrated foods because of inadequate water supplies.

It is estimated that thermal processing of meat costs from 0.8 to 5 cents/lb and that frozen-food processing costs from 2 to 3.5 cents/lb. Estimated freeze-dehydration processing costs of 2 to 8 cents/lb and irradiation processing costs of 1 to 6 cents/lb were compared with the first two methods to show that the processes were all economically competitive.

A mobilization base reserve of a 15-month supply of rations containing irradiated meat components could be obtained by establishing a production base and operating for 1 year nine 100-kw electron accelerators per million men supplied. On the assumption that no more than 50 percent of the meat components of combat rations would actually be irradiated, the 1-year processing time and number of accelerators can be reduced. The research irradiation facility to be built at Natick, Mass., could be pressed into emergency production by addition of production-type conveyer systems and other equipment for the inefficient annual production of about a 1-year supply for 60,000 men.

A total lead time of about 2 years would be required to establish a production base and produce the 15-month reserve supply described. The

accelerators are estimated to cost a total of $1.0 million to $1.8 million per 1 million men. The total initial cost of the 15-month reserve (irradiation facilities plus meat) would be approximately $58 million per 1 million men.

CONCLUSIONS

1. An accelerated rate of research is necessary to complete wholesomeness studies and to overcome developmental problems relating to flexible packaging and acceptability if irradiated meats are to be available to the armed forces for general use before the middle of the 1965–1975 time frame.

2. A ready-to-eat individual combat meal, with irradiated food components in a flexible package, is urgently needed for the best operational ration support of infantry, airborne, STRAC, and Marine Corps units.

3. The use of rations containing irradiated foods instead of B and C rations and the elimination of field kitchens in general war would result in logistical savings equivalent to 99,000 tons of fuel per year per 2 million men in the theater of operations.

4. The logistical savings gained by employing only dehydrated foods instead of B and C rations would be equivalent to 91,000 tons of fuel per year per 2 million men.

5. In 1965–1975 irradiated foods could have a distinctive advantage over all other types of foods in providing an operationally suitable individual combat meal that would be well received by fighting men.

6. The estimated cost of radiation processing of foods would be competitive with the costs of the thermal canning, freezing, and freeze-dehydration processes.

7. About 2 years would be required to obtain a mobilization base composed of a 15-month reserve supply of rations with irradiated meats comprising 50 percent of the meat components. This time includes the estimated 9 to 12 months required to establish radiation facilities and the 12 months required to process the rations.

8. To process the 15-month supply of rations, five 100-kw accelerators per million men would be required at a cost of $1 million to $1.8 million.

RECOMMENDATIONS

1. The Army should accelerate its research in the irradiated foods program sufficiently to:

(a) Establish the wholesomeness and safety of radiation-sterilized meats at the earliest practicable date.

(b) Overcome developmental problems relating to packaging, storage, and acceptability of radiation-sterilized foods, especially meats, to attain a

suitable component for the ready-to-eat individual combat meal early in the 1965–1975 time frame.

2. The Army should continue its research for the development of freeze-dehydrated foods to attain suitable operational quick-serve rations for small-group feeding early in the 1965–1975 time frame.

RADIATION-PROCESSED FOODS AS A COMPONENT OF THE ARMED FORCES FEEDING SYSTEMS

ABBREVIATIONS

AEC	Atomic Energy Commission
APC	armored personnel carrier
CBI	China-Burma-India
CDEC	Combat Development Experimentation Center
CONUS	Continental United States
CDOG	Combat Development Objectives Guide
LTC	light-truck company
Mrad	megarad
POL	petroleum, oils, and lubricants
QMC	Quartermaster Corps
QMR	qualitative materiel requirement
QMRECOMD	Quartermaster Research and Engineering Command
STRAC	Strategic Army Corps
TQMG	The Quartermaster General
TSG	The Surgeon General
USCONARC	United States Continental Army Command

INTRODUCTION

The purpose of this paper is to investigate the possible operational, economic, and logistical advantages that might accrue to the armed forces through the introduction of radiation-processed foods into the feeding system during the 1965–1975 time frame. Because radiation-processing technology is still undergoing development, a study of this technology is germane to the investigation. This study is intended to provide a basis to enable the Army to determine requirements for the irradiated-food research program and to assist the Army in making decisions regarding the construction and operation of a pilot plant for radiation processing of foods. Radiation-processed foods and foods processed by other means are compared for best operational ration support of military personnel in a theater of operations.

The work described in this paper was carried out in coordination with the Army's revised irradiated-food research program by request of TQMG and as authorized by the Chief of Research and Development.

The scope of this paper includes an analysis of the current technological status of radiation preservation of foods and the additional research effort needed to attain fully acceptable products for incorporation into military rations. Attention was given to various concepts of military feeding and the tactical operational requirements of various types of armed-forces units for support rations. Particular consideration was given to the logistical implications involved in the integration of irradiated components in military rations, including savings in manpower, storage, equipment, supplies, and dollar costs. The costs of processing, storing, and transporting irradiated foods were estimated and compared with estimated costs of the freeze-dehydration process and the costs of the commercial canning and freezing processes. Investigations were made of the types, availability, efficiency, and costs of different sources of radiation that could be used for processing foods. The feasibility of establishing a mobilization base containing irradiated meats as ration components was examined, and the number and cost of accelerators needed for a production base was estimated.

For the purpose of an unrestricted analysis of the logistical and economic advantages of using irradiated foods, these portions of the study only were conducted with the assumption that the present inadequacies and questions regarding the technological status of radiation processing of foods would be satisfactorily improved or answered during the time frame of reference. This assumption was not applied to the sections of the paper dealing with radiation-processing technology and feeding concepts.

RADIATION-STERILIZATION TECHNOLOGY

Radiation preservation of food can be accomplished by either sterilizing the food at doses of 2.5 to 4.5 Mrad or "pasteurizing" the food at doses normally less than 1 Mrad. The latter method extends the useful storage life of fresh foods for a few days or longer under the usually employed storage conditions. Radiopasteurization is an important contribution to food preservation and should have application in future markets for both civilian and military use. The Army has conducted much research on this technique, and under the revised National Food Irradiation Research Program, final research and developmental efforts in this area are being directed by the Atomic Energy Commission (AEC). However, because of the interest of the armed forces in obtaining foods, especially meats, that can be kept in a fresh-like condition for longer periods of time and without necessity of refrigeration, the greatest emphasis of the radiation-preservation research conducted by the Quartermaster Corps (QMC) is on the development of radiation-sterilized foods.

Investigation of the safety and economy of the various means by which food can be processed by ionizing radiation shows that cost of operation and biological effects could limit the choice of radiation sources. The various sources of ionizing radiation that have been examined for this process include radioactive isotopes such as Co^{60} and Cs^{137}, spent reactor fuels, and high-energy electron machines such as linear accelerators, Van de Graaff machines, and rectifiers. Although Co^{60} is a clean, penetrating gamma source and a good research tool, radioactive isotopes such as this may find limited use for commercial production of irradiated foods because of the large quantities required, in terms of curies, to maintain the dose rate or dwell time of the food within practical bounds. Its use has been avoided in commercial sterilization of pharmaceutical products for similar reasons and because of the complex engineering problem that would be involved in ensuring a consistent sterilizing dose to a large number of individual items.[1]

The employment of machines producing electrons involves a problem of depth of penetration of the food to be sterilized, in that each 1 mev of electrons will penetrate only about $\frac{1}{6}$ in., and the higher-energy electrons, above 10 mev, can cause small amounts of induced radioactivity to appear in the food.[2,3,4] Although this may place a limit on the thickness of the food that can safely be sterilized, parcels of meat of single-portion size would present no difficulty in this regard since electron sources of energy level below 10 mev can be efficiently used.

INDUCED RADIOACTIVITY

The problem of induced radioactivity in foods should not prevent the useful application of radiation processing to foods if the beam energies are kept as low as possible consistent with efficient processing of the items. Considerable research effort has been spent on characterizing and quantifying induced radioactivity in foods. In general these studies show that the amounts of induced activity from various radiation sources is extremely small.[2,5,6,7] The amount of induced radioactivity in foods depends on the type of radiation used, the beam-energy level, and the kind and quantity of precursor elements present in the food to be irradiated. Glass and Smith[2] point out that the average dose that an individual receives from natural sources (150 mr/year) is much greater than the dose that would be received from an annual consumption of 1200 lb of 24-mev electron-irradiated food (0.26 mr/year). They further show by example that individuals would receive a much smaller radiation dose from consumption of radiation-processed food than would be received by (a) moving from a wooden to a brick house, (b) moving from New York to Denver, or (c) spending the year mostly in a crowd of people.[2,5] Although the objective purpose of medical scientists is to determine whether the consumption of radiation-sterilized foods would add biologically significant amounts of induced activity to natural levels, even extremely small doses received from ingesting irradiated food would be objectionable in the light of the present food-additives amendment to the Federal Food, Drug, and Cosmetic Act.[8] This law may be changed when adequate proof of the safety of irradiated foods can be provided. The safety of irradiated foods from induced radiation will require proof that the particular foods concerned do not have radioactivity levels that are distinguishable from normal background levels.[9]

TECHNOLOGY

The establishment of a radiation dose necessary to sterilize meats on a full-scale production basis has involved a large amount of experimental research and the application of safety factors to ensure a well-preserved product. It has been found that a spore-forming bacterium, Clostridium botulinum, is the most radiation-resistant food-spoilage microorganism of importance present in meats. Accordingly the radiation-dose requirement is aimed at that dose necessary to reduce the probability of live spores surviving the preservation process to one chance in a billion. This dose was determined to be approximately 4.5 Mrad, based on the possibility of very heavy Cl. botulinum contamination of the meat before processing. Additional margins include the fact that the actual contamination of meat with Cl. botulinum is usually low and that when such contamination occurs it is generally on the exposed surfaces rather than within the tissues of the meat. Acid foods (below pH 4.5), represented by many fruits and vegetables, do not present as favorable a medium for the survival of Cl. botulinum and thus can be radiation sterilized at only about 2.4 Mrad.

Although the 4.5-Mrad dose destroys the microorganisms that would spoil the food on storage, another cause of food spoilage remains—the food enzymes

that continue to cause chemical breakdown of the food. In thermal processing of foods (canning) both microorganisms and enzymes are destroyed by heat. In frozen and freeze-dehydrated foods the microorganisms and enzymes are not destroyed, but their action on the food is effectively retarded. This is often accomplished in frozen foods by blanching and then quickly reducing the temperature to the frozen state, where enzyme activity and multiplication of microorganisms are arrested. In the case of freeze-dehydrated foods, it is the very dry state of the food (less than 2 percent residual moisture) that prevents the spoilage activity. For radiation processing of foods it is undesirable to increase the radiation dose to the very high level that would be required to inactivate the food enzymes. Thus in this process meats are heated briefly to an internal temperature of about 160°F to destroy the enzymes and then are treated by irradiation. The degree of change in the molecular structure of the meat by the radiation process is reported to be small and has been estimated at less than a 0.02 percent rupture of chemical bonds following the absorption of a 5-Mrad dose.[6]

PACKAGING

The need to decrease weight and volume of military rations has influenced research requirements for the attainment of lightweight, flexible containers. The discomfort experienced by individuals in combat from carrying several days' rations in hard metal cans has also added to the need for suitable flexible containers. Such packaging must be able to withstand rough handling and the effects of heat, cold, and moisture. Many materials have been examined for the purpose. Plastics and plastic-coated metal foils show the most promise for freeze-dehydrated foods and irradiated foods. The effects of radiation sterilization of food through the package, however, places added requirements on the characteristics of the package material. The packaging of radiation-sterilized food must be adequate to maintain the sterility of the food after processing by protecting against microbial contamination. The irradiation of many of the plastics was found to produce objectionable odors, changes in structural strength, poor sealing qualities, or chemical changes that could result in undesirable additives to the food.[10] Radiation from gamma or high-energy electron sources causes free radicals to form in the plastics and can produce cross-linking or chain scission of the molecules making up the material. At the same time unsaturated bonds, hydrogen, and other gases may be formed which increase the porosity of the plastic. Different effects and degrees of effect are obtained according to the specific chemical structure of each material. Deterioration of all the plastics increases as the energy of the radiation is increased.[10]

Experiments are still under way to determine such problems as the amount of stress-cracking of certain plastics and the extent of formation of extractible substances into a food during irradiation. However, no completely suitable plastic is yet available in which to package irradiated foods for use by the armed forces.[11]

The flexible packaging of freeze-dehydrated foods has unique problems also. One of these is that some of the dehydrated products are sharp and hard enough to puncture weak plastic containers. Another is that the packaging mus

have sufficient rigidity to protect fragile freeze-dehydrated foods from crushing. To solve this problem at present freeze-dehydrated foods are packaged in plastic-foil laminates placed inside cardboard cartons that are expansible to permit addition of reconstituting water directly into the package.

Irradiated foods can also be packaged in rigid containers such as the tin-plated steel or aluminum cans used for thermally processed foods. As with thermal processing, these cans require an enamel lining to prevent chemical spoilage. A number of can coatings have been examined, from which three types of enamels have been selected that collectively provide satisfactory linings for all irradiated products tested.[12] All containers, either coated metal cans or plastic, were observed to evolve hydrogen gas during irradiation, which may cause swelling of the containers. Although this does not damage the food, it could cause the user to become confused between these and containers that swell from gases emitted during food decomposition.[11]

WHOLESOMENESS

All food-processing methods have some small effect on wholesomeness of the foods. Radiation processing has been and continues to be examined in detail for any changes produced by irradiation that could result in unwholesomeness of the food.

To appreciate some of the factors that enter into determinations of wholesomeness, some comments on the effects of radiation on potential toxicity are in order. As stated earlier a radiation dose of about 5 Mrad causes the rupture of less than 0.02 percent of the chemical bonds of the food. These degradation products, although present in very small quantities, could have toxic properties. In the reaction, free radicals such as the peroxides are formed that initiate oxidation reactions, and structural alterations may occur in vitamins, carbohydrates, lipids, proteins, and other compounds found in foods.[13] The complexity of foods makes possible very large numbers of reactions producing such changes, and each type of food represents a different chemical system. Thus it has been necessary to conduct detailed and carefully controlled experimental investigations, including animal feeding studies, to determine whether specific irradiated foods have acquired any toxic or injurious substances or have become nutritionally inadequate. The nutrition and toxicity studies that resulted with radiation-processed foods are far more extensive than those for foods processed by any other means.

Investigations of the possible toxicity of radiation-processed foods began in 1954 with short-term animal feeding studies. The method involved feeding rats irradiated food at a level of 35 percent of the dry solids of the diet during an 8-week period. By 1957 a summary of the results listed 40 food items that had been found nontoxic, including such meat items as beef, corned beef, bacon, frankfurters, ham, sausage, salmon, and shrimp.[13] As the short-term feeding test continued, other foods were added to the list, including such additional meats as pork, chicken, and sea foods.

After the short-term animal feeding tests were well under way, longer-term tests were initiated to determine possible chronic toxicity effects and nutritional adequacy of the foods. In some of these studies rats were fed an

irradiated-food diet through several generations and were studied for weight gain, reproduction, longevity, lactation, and evidence of metabolic changes. Standard assay methods also were conducted for nutritional changes in the irradiated foods. It became apparent very soon that considerable vitamin loss and some amino acid loss occurs when food is sterilized by radiation. However, the vitamin destruction is of the same general order of magnitude as destruction by heat processing. Vitamin supplementation restores this inadequacy inexpensively.[7,14–16]

A number of anomalies were observed in the long-term feeding studies, many of which were at first considered to be caused by toxic substances in the irradiated food. However, later analyses of the experimental procedures and animals used, reexamination of the experimental results, and repetition of the experiments showed that most of the observed anomalies were not manifestations of toxicity of irradiated food but were caused by such things as nutritional inadequacies in the total diet or by factors independent of the irradiation of the food.[7] In a number of cases the anomalies resulted from destruction of vitamins in the foods by the radiation processing and could be corrected by supplementing with vitamins and/or amino acids in the diet.

Although the long-term animal feeding studies have been completed with 21 selected food items, histopathology examinations of the experimental animals will continue until their completion early in 1962. A few of the anomalies appear to require further research for a thorough explanation of their cause or for determining the mechanism of coincident small biochemical changes that were observed in some cases, although these changes did not show evidence of effects on the health of the animals. These anomalies are discussed below.

Fertility Rate. Female beagles fed a diet of irradiated beef showed a reduced litter size, suggesting an effect on fertility rates, although there was no correlation between the amount of radiation and the conceptual problems.[17] The investigator subsequently reported that the reduced litter size may be due to lowered amounts of vitamin E in the diet.[18] This research project continues under two separate investigators, and employs a larger number of dogs (60).

Hemorrhagic Syndrome. Rats fed irradiated beef have been observed to acquire increased prothrombin times and die from hemorrhage. The results of feeding experiments by several investigators show that (a) irradiation destroys vitamin K in the beef[19] as well as small amounts of some of the essential amino acids; (b) the rats' level of intestinally synthesized vitamin K is not affected by irradiation of the food;[20] (c) rats fed irradiated beef stew did not develop the syndrome;[21] (d) addition of vitamin K to the diet will correct the hemorrhage and elevated prothrombin levels of the blood;[11] and (e) the addition of 2 percent D.L. methionine increased the efficiency of the vitamin K supplementation.[22] The hemorrhagic syndrome was found only in rats. Although the problem seems resolved with these findings, interesting subjects for biochemical studies on rats deficient in vitamin K presented themselves during these investigations, including the role of factor V; and their possible relation to irradiated foods encourages continuation of these studies.

Auricular Lesions. In 1958, mice fed an irradiated diet were found by a single investigator (Monsen) to develop a swelling and rupture of the left auricle.[23] The diet consisted of the following irradiated foods: pork, chicken, carrots, white potatoes, and evaporated milk. As of January 1961, 130 of the

original 188 male mice were dead—60 of the dead exhibiting the heart lesions (not necessarily the cause of death). At the same time 139 of the original 189 female mice were dead, with 49 of the dead showing heart lesions.[24] However, similar lesions were recently observed in untreated mice at the Argonne National Laboratory.[18] When Monsen placed mice on a diet consisting solely of irradiated or unirradiated evaporated milk (singled out of the earlier diet), the data presented in Table 1 were obtained, showing that the evaporated milk alone could have been responsible for the incidence of heart lesions previously observed.[23] Research is continuing to determine what mechanism actually causes the phenomenon in certain strains of mice.[13]

TABLE 1

RESULTS OF FEEDING EXPERIMENTS WITH MICE ON A DIET CONSISTING ENTIRELY OF EVAPORATED MILK [23]

Diet	No. of animals	Average life span, days	Incidence of heart lesions, %
Irradiated evaporated milk			
Cooked, no vitamins	24	64	61
Cooked, vitamins added	24	76	80
Unirradiated evaporated milk			
Cooked, no vitamins	24	78	100
Cooked, vitamins added	24	81	85

Four short-term human feeding tests were also conducted for safety and wholesomeness of irradiated foods at the Army Medical Nutrition Laboratory, Fitzsimmons Army Hospital, Denver, Colo.[25] After the irradiated foods had been tested for toxicity in animals and evaluated for palatability by a panel of professional tasters, they were fed to 18 human volunteers for two periods of 15 days separated by an interval of 3 to 7 days. During the first 15-day period half the subjects received the irradiated-food diet and the others received a control diet; during the second 15-day period of each study the situation was reversed. The men who consumed the foods were followed carefully by physical examinations and clinical laboratory tests for a period of 1 year after feeding. A period of several months was allowed between each study to prevent accumulation of possible toxic effects. In the first study approximately 35 percent of the total calories were supplied as irradiated food; in the second, 60 percent; in the third, 80 percent; and in the last, about 100 percent. Forty-two items were included. At the conclusion no evidence could be found of any toxic effects caused by the irradiation processing of the food. Physical examinations showed no abnormalities except those common in a group of young men observed for this period of time. Electrocardiograms showed no significant abnormalities. There were no changes in blood pressure, pulse, respiration, or body temperature except those associated with colds and other disorders unrelated to the study. Other laboratory tests showed no changes that could be related to the feeding of irradiated food.

Subsequently several additional studies of this type were conducted at the Medical Nutrition Laboratory with 19 irradiated foods, including pork, codfish,

bacon, chicken, shrimp, tuna, and various fruits and vegetables.[26,27] Again after careful clinical and laboratory examination no abnormalities or toxic effects attributable to the irradiated foods were found in the test subjects.

It is evident from the foregoing comments that final details of the wholesomeness and toxicity studies on radiation-processed foods will require about 3 years for completion. As of January 1961 the Advisory Committee on Nutrition to TSG was not willing to recommend total clearance of irradiated foods on the basis of available findings. The Committee concurred with TSG in a recommendation that additional research be conducted.[18]

ACCEPTABILITY AND STORAGE

Radiation-Processed Foods

The exposure of food to sterilizing doses of ionizing radiation tends to produce organoleptic changes that are objectionable to the consumer. They include off-flavors, off-odors, and changes in color and texture. The changes become more pronounced as the radiation dose is increased. Thus it has been necessary to conduct considerable research on radiation-processing techniques in order to obtain acceptable meats at a dose of 4.5 Mrad.

Beef. Off-flavors are especially difficult to control in beef, which has led to the much-publicized comment that irradiated beef tastes like "the odor of a wet dog." Efforts to improve the acceptability of irradiated beef have included processing the meat with various condiments, tomato by-products, sodium nitrate, and other additives to mask or remove the off-flavor. Experimental irradiation of beef at temperatures well below freezing has also shown some improvement in flavor, odor, taste, color, and texture.[7] The practicality of this technique remains to be proved. Vacuum packing also is used to reduce the available oxygen in the irradiated container as well as to reduce the hydrogen swelling.

Because of the importance of beef in the American diet, a large program of basic research on the mechanism of irradiation changes has been undertaken. Numerous chemical compounds have been isolated and identified that may be contributory to the irradiation flavors. Through these studies and improvement in irradiation techniques, radiation-processed beef can now be prepared as an acceptable product according to taste-panel tests conducted by QMC. Enzyme-inactivated rib-eye beefsteaks irradiated at 4.5 Mrad have remained stable for 25 months at 70°F and 16 months at 100°F and were "liked moderately" during this period.[28] Other tests showed less favorable results; for example, beef roasts, beefsteaks, and ground beef were enzyme inactivated by an internal temperature of 160°F, treated with charcoal salt and condensed wood smoke, packaged under nitrogen, and irradiated with 4.8 Mrad. These products were reported as acceptable for 8 months at 72°F. No data were available on higher storage temperatures. Spanish steaks irradiated with 4.5 Mrad have been found acceptable for 4 months at 72°F, and some samples were acceptable after 8 months of storage.[28]

The acceptability tests for beef, just described, and for other irradiated foods were conducted by feeding subjects irradiated foods as components of regular meals and requiring the subjects to record their reaction to the foods

on a graded scale devised by QMC. An example of this scale is shown in Fig. 1. At the end of each study the subjects were usually interviewed in order to gather any impressions of differences they noted in color, texture, flavor, and odor among the foods served. Using taste panels many acceptability studies were conducted on meats irradiated at 2 to 3 Mrad after storage times up to 9 months. However, the determination that a 4.5-Mrad dose is required for safe sterilization of meats makes discussion of these results inappropriate here.

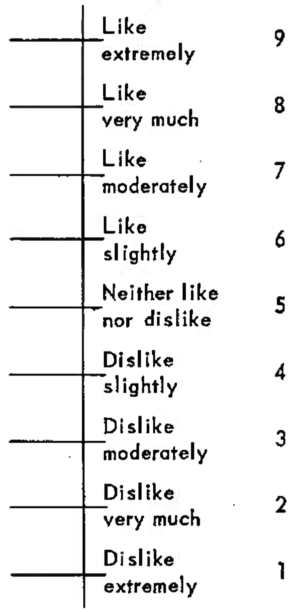

Fig. 1—Example of Grading Scale Used in Taste-Panel Tests of Irradiated Foods

Pork. Results of studies on pork chops that were enzyme inactivated by internal temperature of 160 to 180°F and irradiated with 5 Mrad show that the pork chops were not acceptable to taste panels after 6 months of storage at 72°F.[28] Other studies on pork chops that were enzyme inactivated, irradiated with 4.5 Mrad, and packed with activated-charcoal packets showed more favorable results. In these tests the pork chops remained acceptable in flavor and stable for at least 25 months at 70°F and for 16 months at 100°F.

One group of experiments on roast pork loin irradiated with 4.5 Mrad and stored at 70°F indicated that the roast pork remained stable for at least 5 months and the acceptability, although low, was equal to that of the frozen controls. Better results were obtained with roast pork loin that was enzyme inactivated, irradiated with 4.5 Mrad, and packed with activated-charcoal packets. In the latter tests the roast pork loin remained stable for at least 25 months at 70°F and for 16 months at 100°F. Efforts to store irradiated products containing pork and gravy or pork and barbecue sauce were unsuccessful according to acceptability grading scores.

Ham and Bacon. Examination of baked ham that had been irradiated with 4.5 Mrad showed that the product remained stable and acceptable for over 310 days in storage at 40°F, 70°F, and 100°F, although the taste panels gave higher preference scores to thermally processed ham steaks. Fried ham was tested after irradiation with 4.5 Mrad and was found stable and acceptable for over 310 days of storage at 40° F and 70° F and for over 128 days at 100° F.[28]

Bacon that was irradiated with only 2.5 Mrad remained stable and acceptable for at least 12 months at 72°F and for 6 months at 100°F. The preference scores indicated that the irradiated bacon, after aging for about 1 month, was almost as acceptable as fresh bacon.

Chicken. An examination of chicken parts that had been enzyme inactivated, irradiated with 4.5 Mrad, and packed with activated-charcoal packets showed that they remained stable for over 16 months at either 70°F or 100°F with good acceptability. Boned, rolled, and sliced chicken that was irradiated with 4.5 Mrad was still undergoing storage acceptability tests at the time of data collection and showed that the chicken remained stable and acceptable for at least 194 days at both 70°F and 100°F. Acceptance was slightly lower than similarly prepared canned chicken.[28]

Earlier attempts at preserving chicken with only 3 Mrad after enzyme inactivation resulted in a product that was acceptable to a taste panel after storage for 4 years and 7 months at 72°F when it was served as chicken cacciatore.

Shrimp. Acceptability tests of enzyme-inactivated shrimp that had been irradiated with 4.5 Mrad showed that the product remained stable for 6 months at 72°F and only about 3 months at 100°F. Acceptability was good during these storage times.[28]

Troop Evaluation Tests. Troop evaluation tests performed at Ft Lee, Va., in the spring of 1958 concluded that radiation-preserved pork processed with 4.5 Mrad and stored in cans at "room temperature" for 10 months was equally acceptable as fresh pork when served as a barbecued roast. Prepared as roast pork with gravy, the radiation-processed meat was equally acceptable. Radiation-processed sliced bacon, stored in cans for 12 months at "room temperature" and prepared by oven frying, was equally acceptable as freshly bought bacon in these tests. About 60 volunteers were involved in each sampling.[29]

In November–December 1958, additional field evaluation tests were conducted at Ft Lee with about 100 volunteers divided into two groups alternating as control and test groups. Six irradiated foods were tested for acceptability after 3 months of storage at room temperature with the following results:[30]

(a) Fried chicken—acceptable, but unirradiated preferred
(b) Chicken stew—liked as well as unirradiated
(c) Shrimp—liked, but fresh slightly preferred
(d) Diced carrots—not liked
(e) Fruit compote—equally well liked as unirradiated when served as spiced fruit pie
(f) Pineapple jam—liked as well as unirradiated

Freeze-Dehydrated Foods

Freeze-dehydrated precooked fish patties can be stored for at least 12 months at either 70°F or 100°F and remain acceptable. Either precooked or raw freeze-dehydrated shrimp were also demonstrated to remain acceptable during 12 months at either 70°F or 100°F. Precooked freeze-dehydrated products such as chicken and rice, beef and noodles, and spaghetti with meat and tomato sauce remained acceptable for 12 months. Freeze-dehydrated, raw, boneless pork chops remained acceptable for 42 months at 70°F and for 7 to 12 months at 90°F and 100°F. Precooked freeze-dehydrated swiss steak has remained acceptable for 15 months at 70°F and for 10 months at 100°F.[28]

DISCUSSION

It can be seen from the information presented above that significant improvement in the storage times coincident with good acceptability is needed in both irradiated meats and freeze-dehydrated meats especially at higher storage temperatures. The continuing research effort to improve processing and packaging technology could increase the shelf life of these products to an acceptable operational level by 1965.

In view of recommendations to continue wholesomeness studies and because of time required to overcome developmental problems relating to flexible packaging and acceptability, it appears unlikely that irradiated meats will be available to the armed forces for general use by the beginning of the 1965–1975 time frame. However, the rate of attainment of research results should allow the capability of employing irradiated foods in rations later in that period.

FEEDING CONCEPTS AND OPERATIONAL REQUIREMENTS

PRESENT AND FUTURE FEEDING CONCEPTS

The field rations issued to ground-warfare units of US armed forces during recent wars consisted primarily of B, C, and K rations. The B ration, a processed food ration consisting primarily of canned items, was distributed in bulk lots and was prepared by organic food service personnel using field-kitchen equipment. Under cover of darkness such food was often carried to front-line soldiers in insulated containers and doled out into individual mess gear. Noon meals for units in direct contact with the enemy consisted of either the thermally processed canned C ration or the K ration. The latter two rations were also employed as individual meals for as long as necessary for individuals employed on missions that prevented their access to a field mess. However, C and K rations generally became monotonous during continuous use for a few weeks. For small crews or squads who were required to be separated for long periods from their parent units, 5-in-1 and 10-in-1 rations (employing B-ration components) were developed in units containing three complete meals for the 5 or 10 men.

Although the exact structure of the future field army is not established, planners anticipate the need for highly mobile, well-dispersed units in the combat area. To meet these needs, future feeding concepts involve the elimination of food service personnel from fighting units in the field, along with their field kitchens, equipment, and vehicles. Rations for these units would be distributed in one-meal modules in sizes for 25 men, 6 men, and 1 man according to the daily situation requirements of the user troops. These rations would contain primarily dehydrated foods or irradiated foods.

Company or larger-group feeding situations might continue to be feasible in rear-area installations, allowing the use of food service personnel for meal preparation. However, the allocation of organic mess personnel and full field messing equipment to fighting units in a theater of operations would be wasteful in terms of subsistence development potential in irradiated and dehydrated foods.[31] For planning purposes QMC has estimated that a field army in future combat will require approximately 18 percent individual meals, 48 percent crew- or squad-type meals, and 34 percent large-group-type meals. Thus about 66 percent of the future field army will subsist on packaged rations requiring little or no preparation.[31]

Planning for a feeding system is based on the expected combat-situation requirements and the best logistical support to meet these requirements. The plan presented here assumes that freeze-dehydrated foods and irradiated foods

would be available for use during the 1965–1975 time frame to fulfill the demand for increased efficiency of supplying operational rations. This plan is compared with the present feeding-system capabilities in a theater of operations as shown in Fig. 2. As indicated, with the present rations and feeding system, the bulk B ration (and soon the "unitized" B ration) prepared by organic mess personnel would be fed to most troops as far forward as the tactical situation would permit. Where small crews or squads are temporarily separated from their parent units and cannot return to a centralized mess the 5-in-1 canned ration could be used. For similar situations and for individuals in close contact with the enemy, the C ration would be used, either hot or cold, as the situation would permit. For emergency use, to dispel hunger for a few hours, the assault food packet could be employed.

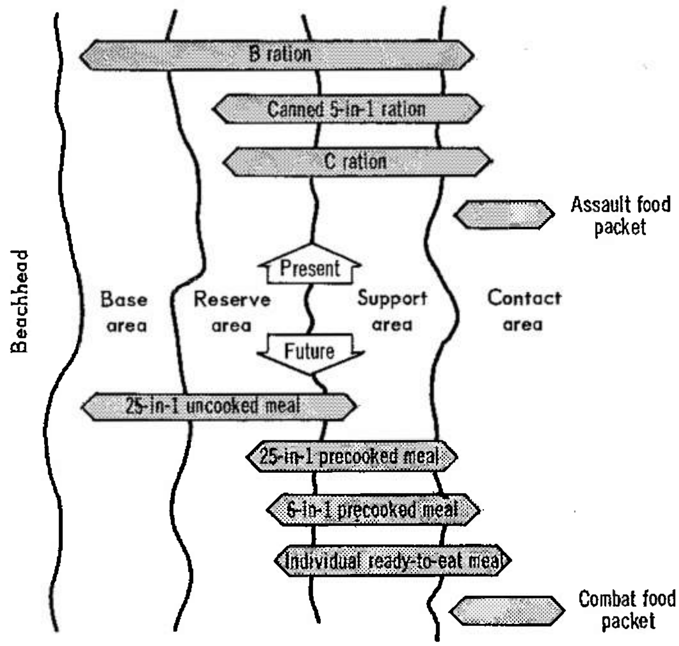

Fig. 2—Present and Future Feeding Concepts

In the future feeding concept shown, meal modules would be employed as follows:

(a) The 25-in-1 uncooked meal might be used behind the contact area. This ration will contain canned, dehydrated, and irradiated foods, and will be served by trained food service personnel in a unit-mess type of feeding.

(b) From the reserve area forward into the contact area the 25-in-1 precooked quick-serve meal would be used where the tactical situation precludes the preparation and serving of the 25-in-1 uncooked meal. This ration will contain precooked freeze-dehydrated foods as the major component, which will be prepared by one or two individuals by pouring hot water directly into the food packages and serving it on disposable trays packed in the carton with

the meal. Trained food service personnel would not ordinarily be involved. Under some circumstances precooked irradiated meats might be used in place of freeze-dehydrated meats.

(c) In situations where small groups are dispersed from their units for long periods, the 6-in-1 precooked ready-to-serve meal would be used. It will contain the same type of foods as the 25-in-1 meal.

(d) In the contact area especially and under certain conditions to the rear, the tactical situation will often require the use of an individual ready-to-eat meal. This will contain precooked irradiated foods that will normally be eaten cold but could be warmed by the individual when his situation will allow it. Flexible packaging is needed for this ration.

(e) Individuals would also be issued an individual combat food packet for emergency use. This will be a small, compressed, high-caloric-content food item totaling about 1000 calories. This is not intended to replace a meal when other rations can be provided but is to be capable of sustaining a man for as long as 2 to 10 days under emergency situations without loss of efficiency and without irreversible physiological damage.

In November 1960 TQMG issued a position paper on subsistence support in a theater of operations.[32] The paper states that during the 1960–1970 time frame feeding will be accomplished to the greatest extent possible by using A and B rations and unitized 25-man B rations. The food items are to be primarily canned, uncooked dehydrated, and precooked dehydrated foods, plus ingredients for breadmaking. The paper states that this is predicated on technological and production-base considerations and developmental problems. According to the position paper, the uncooked freeze-dehydrated foods are not expected to be available until 1968, which makes necessary the use of field kitchens and trained food service personnel for group feeding. Small groups, it is stated, will have to continue to rely on the canned 5-in-1 ration, eaten either hot or cold directly out of the cans. The quick-serve 6-in-1 freeze-dehydrated meal is not expected to be available to them until 1969. Troops requiring individual meals because of tactical situations preventing their feeding with groups will have to rely on the canned individual combat meal, "for the present and indefinite future," as they did in WWII.[32]

The position paper is thus pessimistic toward the capability of research and development to provide the best means by which tactical operational requirements for rations in highly mobile combat situations during 1965–1975 can be met. Since the freeze-dehydrated foods and irradiated foods needed for military combat rations are not identical to civilian requirements for processed foods, production capabilities, if needed, will have to be established from military funds instead of those of the American food industry. USCONARC-approved military characteristics for operational rations as provided in January 1961 include (a) the 25-man uncooked meal requiring no refrigeration, and making maximum use of dehydrated and irradiated foods; (b) the 20- and 6-man quick-serve meals composed primarily of dehydrated foods that can be reconstituted with hot or cold water in not more than 20 min; and (c) the individual ready-to-eat meal containing dehydrated and irradiated components that are highly acceptable when eaten cold, without any preparation or mess gear being required.[33]

The examination of tactical utility of the proposed rations is restricted to units of division size and smaller. Emphasis is directed toward feeding problems of the individual soldier and the small group, from contact area through reserve and support areas to the rear boundary of the division. Consideration is given to the characteristic requirements of maneuver and service elements of the division and to the requirements of specialized units in the several arms. Published information pertinent to the problem was supplemented by conferences with military personnel selected for experience in the areas of interest (see App C).

Ration and feeding-system requirements are primarily a function of the pattern of activity or specific mission of the particular unit. The discussion that follows does not cover all possible areas of military activity, but it presents a fair range of tactical feeding problems and indicates the advantages that might accrue from the use of irradiated foods and freeze-dehydrated foods in rations.

Army

Within an infantry, armored, or airborne division, maneuver and service elements exhibit characteristic needs for combat feeding. The former, frequently in a mobile and isolated situation, needs the capability to feed individuals and small groups with little or no preparation and without the use of skilled personnel. Although current field rations are acceptable, irradiated-food components could provide higher-quality ready-to-eat meals with greater acceptability over extended periods of time in 1965–1975.

Service elements, unless detached for temporary duty (such as wire crews from the division signal company), will only occasionally be required to utilize ready-to-eat meals. To these troops irradiation and freeze-dehydration will offer the advantages of higher-quality, nonperishable rations of wider variety.

Infantry. Although it is anticipated that the infantry soldier will travel mostly in an armored personnel carrier (APC), his weapons are man-portable, and he will still fight on foot whenever the situation or terrain demands that he do so. Thus his food needs are dictated by flexibility. He will be required to rely to a considerable extent on individual rations that he carries, although his vehicle will have the capacity to haul unitized small-group rations for use when time permits. He needs palatable, lightweight, ready-to-eat meals and quick-serve meals packaged with expendable utensils and mess gear in order that his "fighting payload" be as large as possible.

Interviews indicated that there is great need for a lightweight, palatable, and nutritious individual meal of the "sandwich" type, containing bread, cheese, and meat. Irradiated foods would appear particularly suitable for this type of meal.[34]

Armor. Weight and bulk of rations are of less concern to armor than to infantry divisions, and the situation with respect to small-group feeding is better. Current methods employ company messes, prepared in the battalion trains area and sent forward by truck. If practical two hot meals per day will be served, one before dawn and one after dark, with the midday meal consisting

of an individual quick-serve or ready-to-eat item. Armored units anticipate being in maneuver approximately 65 percent of the time, and a 3- to 5-day supply of the current quick-serve ration will be carried on the vehicle (tank or APC) to meet those situations when hot meals cannot be sent forward.[34]

The development of improved fuels, power plants, and weapon systems for armored vehicles will increase their operating range and the duration of their fighting effectiveness. These improvements will increase the requirement for small-group feeding in each vehicle. Irradiated foods and freeze-dehydrated foods in ready-to-eat and quick-serve meals will best meet these requirements.

Artillery. Generally more static than either infantry or armor units, artillery currently has food service personnel assigned to each battery. Each battery must be on 24-hr call, and in movement each will face different problems in displacement and reemplacement in the new battery area. In order that the guns be manned continually, battery feeding extends over a 2-hr period. Tactical doctrine at the US Army Artillery and Missile School includes battery messing in the long-range time frame. Hot meals will be served to battery personnel whenever possible, and an individual feeding capability will usually be needed only by forward observers. For these special duties the ready-to-eat individual combat meal will be needed.[34]

Airborne and STRAC Forces. In the "airhead" concept of employment, the airborne division, in contrast to most regular ground forces, will have the responsibility for a 360-deg defensive coverage with only the essential minimum of resupply. This will require the acceptance of greater austerity in the ration system. During the 5- to 7-day assault phase of an airborne operation, no time is available for food preparation, and each man will enter combat with a canteen of water and minimum rations; in the aerial resupply that precedes ground support, ammunition and POL will be of first importance. An urgent need has been cited for a lightweight ration, preferably no more than one-third the weight of the present individual ration.[34] The individual combat food packet or irradiated meat and cheese sandwiches in flexible packages could be used with better advantage than heavier and bulkier full-sized meals.

STRAC forces face less stringent weight limitations than do airborne units, but they recognize similar needs for austerity in feeding during the initial phases of an operation. STRAC troops will carry a 3-day supply of individual rations and thereafter will depend on the theater supply system. Rations, ammunition, and POL will be delivered through channels established for the anticipated scheme of maneuver. Time required for food preparation must be minimized if the STRAC trooper is to perform all his duties without degradation of effectiveness. STRAC rations should have high caloric content, be palatable and nutritionally adequate, and require little, if any, preparation.[35]

The individual combat meal with irradiated components and unitized group rations with both irradiated and freeze-dehydrated components would meet the requirements of STRAC units. STRAC officers feel that mess personnel are valuable after the assault phase because they serve hot meals, which are good for morale purposes, and they allow fighting troops more time to perform their regular duties.[36]

Special Forces. On the basis of current thinking there appears to be very little requirement for any of the proposed family of combat rations for special

forces. These personnel will live "as and with" the indigenous forces with whom they work and will depend primarily on local sources for food.[37] Earlier planning included a requirement for the individual C ration, but this was dropped in favor of a recently adopted schedule that will provide a minimum monthly food supply during initial phases of the operation, followed by increased rates of supply to support continued activity. This bulk ration supply will include flour, rice, canned bacon or poultry, coffee, tea, tobacco, shaving items, and medical supplies.[38] Where austere conditions can be relaxed, irradiated ready-to-eat and freeze-dehydrated quick-serve meals should be most suited to the tactical requirements.

Marine Corps

The Marine Corps began studying the problem of improving field rations for use in amphibious operations in May 1959, and introduced the "meal, 25-in-1, landing force." This quick-serve ration was found acceptable to troops and was satisfactory for use in battalion, company, and platoon feeding. Subsequent testing, however, found the 25-in-1 and 6-in-1 rations under development by QMC better with respect to ease of preparation, weight, equipment requirements, and adaptability to all field situations. However, Marine Corps forces in an amphibious assault, which may often take 3 days, require lightweight ready-to-eat meals such as provided by the individual combat meal packet or the individual ready-to-eat meal containing irradiated foods.[39]

Navy

Shipboard feeding problems are primarily associated with logistics and morale. The replenishment of stores, including fuel and food, requires the vessel to stop, thus increasing its vulnerability. An improvement in foods that would decrease the number or duration of stops would be of tactical significance. The increased range of modern vessels, as demonstrated with nuclear-powered submarines, requires matching capabilities for food storage on board. Thus the Navy has an urgent, immediate need for "ration-dense" foods with minimum storage and handling requirements.[40] More complex weapons systems requiring additional space for associated equipment will impose further restrictions on food storage space. The ability to store "fresh-like" meat items in non-refrigerated storage space is highly desired. Uncooked irradiated meats are being considered for this purpose. Continued use of canned meats is a cause of dissatisfaction with present rations. However, the Navy has little need for quick-serve or ready-to-eat rations because trained food service personnel and equipment are always available on board a ship.

Air Force

Field-ration requirements for Air Force ground-support personnel and for air crews between missions closely parallel those of rear Army installations. Reductions in weight, bulk, and perishability to permit aerial resupply are desirable, but no special requirements are readily apparent. In-flight feeding introduces some need for what is termed "specialized subsistence."[41] Currently available in-flight food items include the box lunch, in-flight food packet, precooked frozen meal, foil-pack meal, and compact box lunch. In

large aircraft capable of sustained flight for 10 to 18 hr, facilities are available for heating quick-serve or ready-to-eat meals, and relief crew members permit comfortable messing.

In general, fighter-interceptor–type aircraft are restricted in their maximum endurance to less than 4 hr.[42] There is no requirement for airborne feeding in this type of aircraft other than a palatable snack item, primarily of value in breaking the monotony of a noncombat patrol or ferry mission.

Space-flight feeding will undoubtedly introduce new problems with respect to the weightlessness, restricted movement, and limited facilities in an astronaut's environment. Irradiated ready-to-eat meals may serve this purpose more efficiently than other types of processed foods.

Discussion

In summary, feeding requirements for combat are based on the needs of individuals and groups within various types of armed-forces units during tactical situations. An important operational saving in men, kitchens, and refrigerated storage equipment can be made by feeding unitized quick-serve and ready-to-eat meals that contain both freeze-dehydrated and irradiated components to all ground-force maneuver elements in combat. In addition this system would be of considerable tactical advantage in situations requiring high mobility and dispersion of troops. The individual combat meal containing irradiated foods in flexible packages is needed by Marine Corps and Army infantry, airborne, and STRAC units to provide the best ration support to personnel in close contact with the enemy during the 1965–1975 period. When resupply will not be available for several days, the individual combat food packet will best enable assault troops to sustain themselves with the lightest ration load. Both irradiated foods and freeze-dehydrated foods will be required for group feeding. The Navy's requirement for irradiated food is based primarily on its desire for a better-tasting meat ration than the present canned meat. The Air Force's need for irradiated foods and freeze-dehydrated foods is limited mainly to logistical advantages of supply to overseas bases.

RELATIVE URGENCY FOR RATIONS CONTAINING IRRADIATED-FOOD COMPONENTS

There is an urgent operational need for an individual ready-to-eat ration that best supports the tactical mission of Army and Marine Corps units in the type of combat situations expected in the 1965–1975 time frame, as discussed in the preceding subsection. Because irradiated foods appear to have most promise as the major components of this ration, in the form of a flexibly packaged ready-to-eat meal, irradiated foods, especially meats that have acceptable flavor, should be developed as early as possible for official medical approval and should be used for this purpose. Obviously the requirement to conduct all necessary research to establish the safety and wholesomeness of irradiated foods is urgent if medical approval of their use is to be obtained by 1965 or shortly thereafter.

The need for inclusion of irradiated-food items in 25-in-1 and 6-in-1 quick-serve meals appears a little less urgent from an operational viewpoint,

because in special situations where adequate supplies of hot water for rehydration of freeze-dehydrated foods are not available the individual combat meal could be employed. The individual combat food packet is urgently needed for immediate operational use of deployed units of the armed forces in overseas areas and for use by STRAC units. This latter requirement is stated in the Combat Development Objectives Guide, qualitative materiel requirement (CDOG QMR).[43]

FOOD LOGISTICS

INTRODUCTION

With the current emphasis on mobility of US forces vs enemy mass a continuing requirement exists for improved logistical operations to support such mobility. This requirement pervades all classes of supply. Although class I supply is a small fraction of the tonnage of class III fuels, simplified rations do contribute to reducing equipment and manpower requirements and improving mobility.

Since WWII and the Korean War considerable progress has been made toward the development of simplified food logistics. At that time there were no suitable food items, commercial or otherwise, that fulfilled the requirements. In recent years a feeding system based on the concept of quick-serve meals has been in the process of development. Such meals consist largely of precooked freeze-dehydrated foods.

In addition the contribution to health and morale of dispersed mobile troops that may be made by highly acceptable "fresh-like" foods is immeasurable. Fresh foods in quantities sufficient to feed dispersed troops during a general war probably cannot be supplied because of the need for extensive refrigeration facilities. Irradiated foods may provide such highly acceptable ration components, either uncooked or ready-to-eat, without the need for refrigeration.

Today there appear to be two essentially different points of view toward food logistics. One stems from the concept of general war, the other from limited war. General war involves millions of US troops; limited war, tens of thousands. General war involves an enemy that fights with equipment and forces similar to those of the US. Under such conditions the food factors of interest are the savings that freeze-dehydrated food or irradiated food may bring in manpower, trucks, fuel, refrigeration, ocean shipping, and dollar costs—all of which will be large.

In limited war, on the other hand, the costs in manpower, equipment, and dollars are much more modest; even more important are the inhospitable climate, difficult terrain, constant threat of guerrilla action, and the mobility of US forces in the face of these difficulties.

Introduction

One of the important reasons for considering freeze-dehydrated foods and irradiated foods in overseas supply is the possible logistical advantages of such foods. The introduction of these foods overseas may change drastically the WWII feeding system to the extent of eliminating field kitchens, bakery companies, and refrigeration companies. These units require large quantities of heating fuel; trucks with gasoline; cooks, bakers, and drivers; and water.

Not only may field messing be changed but garrison messes may not need to be logistically supported by refrigerated warehouses and ocean-going refrigerator ("reefer") ships. These items require large quantities of materials, construction man-hours, fuel for gasoline-driven refrigerant compressors, and water.

If the use of freeze-dehydrated foods and irradiated foods becomes widespread, the potential logistical savings may become quite substantial. To illustrate the potential of these foods, an army of 2 million men overseas in a theater of operations during 1965–1975 is considered. Examples of such theaters are Western Europe, the heartland of the USSR, or the Chinese mainland. For the purpose of this illustration it is assumed that freeze-dehydrated foods and irradiated foods are technically feasible, nontoxic, and nutritionally adequate. It is assumed also that the use of such foods in a theater is widespread so that field kitchens, bakeries, and all food refrigeration overseas may be eliminated.

For this study the organization and distribution of men in a theater is taken from FM 101-10.[44] Some pertinent data are shown in Tables 2 and 3.

TABLE 2

COMPOSITION OF THEATER SLICE BY ASSIGNMENT[44]

Assignment	Troops
Basic division	13,961
Nondivision	18,540
Theater overhead	24,750
Army	(10,750)
Air Force	(14,000) [a]
Total	57,251

[a]Two Air Force wings including Army support.

Field Equipment

Kitchens. A field kitchen consists of a $2\frac{1}{2}$-ton truck and trailer, field cooking ranges with gasoline-operated fire units, cooking utensils, and tentage. Auxiliary equipment includes insulated food containers for storage, delivery, and dispensing hot foods, and large galvanized cans and immersion heaters for heating water for mess-equipment sanitation. During overseas use these kitchens require gasoline, water, and the services of cooks. Estimated overseas requirements for field kitchens for 2 million men are given in Table 4.[45,46]

TABLE 3

COMPOSITION OF AN OVERSEAS ARMY SLICE[44]

Item	Division	Corps[a]	Army (rounded)[b]
Men			
Armor	14,600	14,600	—
Infantry	13,748	41,244	—
Corps, nondivision	—	74,160[c]	—
Theater overhead	—	99,000[d]	—
Total		229,004	687,000
Field kitchens			
Armor	98	98	—
Infantry	79	237	—
Total		335	1,005
Bakery companies (mobile)	—	—	5
Refrigeration companies (mobile)	—	—	1

[a]Corps has three infantry divisions and one armored division plus non-division troops.

[b]Army has three corps.

[c]$18,540 \times 4$.

[d]$24,750 \times 4$.

TABLE 4

REQUIREMENTS FOR FIELD KITCHENS

(For 2 million men overseas)

Item	Quantity
No. of field kitchens	2,925[a]
Men	14,625[b]
Trucks	2,925
Water, millions of gal/year	
Equipment	213[c]
Men	80[d]
Total	293
Fuel, tons/year	
Trucks	4,100[e]
Cooking	56,000[f]
Pump water	5,130[g]
Total	65,230

[a]From Table 3 $[1005 \times (2 \times 10^6)]/687,000 =$ 2925 field kitchens.

[b]Based on five men per field kitchen.

[c]Based on 200 gal/day/kitchen for washing and rinsing mess trays plus all else not consumed directly by men.[45]

[d]Based on 15 gal/man/day. Truck water requirements are small in comparison.

[e]Based on 2000 miles/year/truck, average fuel consumption of 5 miles/gal, and 7.0 lb/gal.

[f]Based on 15 gal/day/kitchen.

[g]Based on 1 gal of fuel required to pump 200 gal of water at the water source.[46]

Bakery Companies. Mobile bakery companies bake bread for troops in the field but may also be assigned to supplement the production of garrison bakery units as the situation demands. In an around-the-clock operation a mobile bakery company can make bread to serve 96,000 men about 8 oz/man/day.[47]

During overseas use these bakeries require fuel for ovens, electrical generators, and trucks; water; and the services of bakers and truck drivers. Estimated overseas requirements for mobile bakery companies for 2 million men are given in Table 5.

TABLE 5

REQUIREMENTS FOR MOBILE BAKERY COMPANIES
(For 2 million men overseas)

Item	Quantity
No. of bakery companies	15[a]
Men	2130[b]
Trucks	315[c]
Water, millions of gal/year	
Equipment	39[d]
Men	12[e]
Total	51
Fuel, tons/year	
Trucks	2200[f]
Ovens	1150[g]
Electric generators	3950[h]
Pump water	890[i]
Total	8190

[a]From Table 3, $[5 \times (2 \times 10^6)]/687{,}000 = 14.6$ bakery companies.

[b]Based on 142 men/company.[47]

[c]Based on 21 trucks/company.[47]

[d]Based on 100 gal/hr/platoon and three platoons per company.

[e]Based on 15 gal/man/day. Truck water requirements are small in comparison.

[f]Based on 10,000 miles/year/truck, average fuel consumption of 5 miles/gal, and 7.0 lb/gal.

[g]Based on 10 gal/day/oven and six ovens per company.

[h]Based on three generators (25 kw each) per company running continuously; specific fuel consumption = 0.6 lb/hp-hr.

[i]Based on 1 gal of fuel required to pump 200 gal of water at the water source.

Refrigeration Companies. Mobile refrigeration companies deliver perishable foods from depots to supply points, but many also use their semitrailer vans as fixed refrigerators as the situation demands. A mobile refrigeration company can supply 360,000 men with perishables at the rate of $\frac{3}{4}$ lb/man/day provided the round trip from depot to supply point does not exceed 10 hr.[48]

During overseas use these companies require fuel for gasoline-driven refrigerant compressors and trucks, water for men and trucks, and the services of refrigeration mechanics and truck drivers. Estimated overseas requirements for mobile refrigeration companies for 2 million men are given in Table 6.

TABLE 6

REQUIREMENTS FOR MOBILE REFRIGERATION COMPANIES
(For 2 million men overseas)

Item	Quantity
No. of refrigeration companies	3[a]
Men	564[b]
Trucks	165[c]
Water for men, millions of gal/year	3[d]
Fuel, tons/year	
Trucks	1,150[e]
Refrigeration equipment	10,600[f]
Pump water	50[g]
Total	11,800

[a]From Table 3, $[1 \times (2 \times 10^6)]/687{,}000 = 2.9$ refrigeration companies.

[b]Based on 188 men/company.[48]

[c]Based on 55 trucks/company, of which 48 are 7½-ton semitrailers and 7 are 2½-ton trucks.[45]

[d]Based on 15 gal/man/day. Truck water requirements are small in comparison.

[e]Based on 10,000 mile/year/truck, average fuel consumption of 5 miles/gal, and 7.0 lb/gal for both truck types.

[f]Based on 5-hp motors, specific fuel consumption of 0.6 lb/hp-hr, and 7000 hr/year of operation.

[g]Based on 1 gal of fuel required to pump 200 gal of water at the water source.

Refrigerated Warehouses

It is assumed that the use of freeze-dehydrated foods and irradiated foods overseas will eliminate the necessity for refrigerated food. This in turn eliminates the necessity for refrigerated warehouses for food. These warehouses require large quantities of gasoline (for generating electricity), water, construction materials, and man-hours of labor (see Table 7).[49] Thus their elimination may represent a substantial saving in overseas logistical effort.

In this study it is assumed that refrigerated stocks for a 30-day supply are maintained in the theater. For 40,000 men a 30-day supply of perishables requires about 15 refrigerated warehouses 20 by 100 ft each.[45]

It is difficult to estimate accurately what fraction of the men in a theater of operation may receive perishables regularly. A rough estimate may be made, however, from the fact that there is one mobile refrigeration company per Army slice (687,000 men—Table 3) that can deliver perishables regularly to a maximum of 360,000 men. Thus for 2 million men in a theater, the maximum number that may receive perishables regularly is

$$[(2 \times 10^6) \times 360{,}000]/687{,}000 = 1.05 \times 10^6 \text{ men}$$

or about 52 percent. Thus the maximum number of refrigerated warehouses required to supply full A rations is taken to be

$$[(1.05 \times 10^6)/(40{,}000)] \times 15 = 394 \text{ warehouses.}$$

TABLE 7

REQUIREMENTS FOR CONSTRUCTION AND OPERATION OF A REFRIGERATED WAREHOUSE

(Size 20 by 100 ft)

Item	Quantity
Electricity, kw	23
Water, gal/day	100
Materials, tons	76
Man-hours of labor	2400

TABLE 8

FREEZE AND CHILL REQUIREMENTS

(In pounds per man per month of packaged weight)

Item	Freeze	Chill	Total
European Command, WWII	21.7	8.8	30.5
Full A ration	41.9	27.4	69.3

From WWII experience in Europe, however, the freeze-plus-chill packaged weight that was actually supplied was only about 44 percent of that of the full A ration (Table 8).[50] Thus a more realistic warehouse requirement may be $394 \times 0.44 = 173$ refrigerated warehouses. This and other material and service requirements for refrigerated warehouses are listed in Table 9.

New Feeding System

The quantities in Tables 4, 5, 6, and 9 are combined in Table 10 to give the total requirements for trucks, gasoline, water, and men for field kitchens, bakeries, and all food refrigeration. The amounts of men and materials shown in Table 10 are those that may be saved by the elimination of these same facilities in a theater of operations. Field kitchens are particularly wasteful of men, trucks, and fuel. Since bakery and refrigeration companies are less numerous, their total requirements are less than those for kitchens.

Balanced against the potential savings in men and materials (Table 10) are the additions of men and materials that may be required by the widespread use of freeze-dehydrated foods and irradiated foods overseas. Wherever

TABLE 9

REQUIREMENTS FOR REFRIGERATED WAREHOUSES

(For 2 million men overseas, warehouse size, 20 by 100 ft)

Item	Quantity
No. of refrigerated warehouses	173
Men	519[a]
Water, millions of gal/year	
Equipment	6[b]
Men	3[c]
Total	9
Fuel, tons/year	
Electricity generation	12,700[d]
Pump water	110[e]
Total	12,810
Materials, tons	13,100[b]
Man-hours of construction	416,000[b]

[a]Based on three men per warehouse (ORO estimate).

[b]From Table 7.

[c]Based on 15 gal/man/day.

[d]Based on amount of electricity from Table 7, 0.6 lb/hp-hr, and 7000 hr/year operation.

[e]Based on 1 gal of fuel required to pump 200 gal of water at the water source.

TABLE 10

REQUIREMENTS FOR KITCHENS, BAKERIES, AND REFRIGERATION FACILITIES

(For 2 million men overseas)

Facility	Men	Trucks	Water, millions of gal/year	Fuel, tons/year
Field kitchens	14,625	2925	293	65,230
Bakery companies	2,130	315	51	8,190
Refrigeration companies	564	165	3	11,800
Refrigerated warehouses	519	0	9	12,800

garrison messes are used in a theater, the substitution of irradiated meats, fruits, and vegetables for ordinary perishables should not cause any particular increase in manpower, cooking fuel, or vehicles. As mentioned previously, irradiated food may be handled in the same manner as before, with the exception that refrigeration will no longer be required (Tables 6 and 9). For irradiated foods the same warehouse, manpower, and truck requirements will exist but without the fuel required for refrigerant compressors. In garrison messes cooking will require about the same time and fuel as before. Hauling will also require the same effort since there is no decrease in weight or volume of irradiated uncooked foods due to irradiation.

TABLE 11

REQUIREMENTS FOR FREEZE-DEHYDRATED FOODS
(For 2 million men overseas)

Item	Quantity
Water for reconstitution, qt/man/day	3[a]
Consumers, millions of men	0.5[b]
Total water, millions of gal/year	137[c]
Heat for reconstitution, Btu/man/day	1,125[d]
Heating value of gasoline, Btu/lb	20,200
Fuel, tons/year	5,080[e]

[a]Based on 1 qt/man/meal.
[b]Based on 25 percent of 2 million men (ORO estimate).
[c]This requirement partly counterbalances that saved in kitchens and bakeries: 293 + 51 millions of gallons per year (Table 10). Thus the net water saving is about 293 + 51 – 137 = 207 mil gal/year.
[d]Based on 150 Btu/lb for water, plus 10 percent loss to container and 10 percent loss to air.
[e]Based on the use of gasoline and small portable field stoves.

In that part of a theater of operations where freeze-dehydrated quick-serve meals are appropriate, there is a requirement for extra water and for fuel to heat this water. The water and fuel requirements for freeze-dehydrated food shown in Table 11 are based on an assumption that 25 percent of the men in a theater of operations will eat quick-serve meals regularly. One of the advantages of these meals is that no trained cooks or food-handling personnel are required.

For the small fraction of men in a theater that will be in combat situations and isolated from group feeding, cooked, irradiated, ready-to-eat foods may be appropriate. Such foods require no cooking or heating of water. This type of food is logistically the simplest of all. No additional logistical requirements are expected here.

The net fuel savings due to the elimination of field kitchens, bakery companies, and refrigerant compressors that could be obtained by the use of irradiated foods and the introduction of freeze-dehydrated foods are shown in Table 12. It is this amount of fuel that truck companies must supply in the theater and that must be delivered overseas by ocean-going tankers.

Light-Truck Companies (LTCs)

The delivery of bulk fuel by truck is one of the largest problems in theater logistics. In WWII there were relatively long motor lines. In the European theater of operations (ETO) the Red Ball Express routes stretched 350 miles; in the China-Burma-India (CBI) theater the Burma and Lido roads extended over mountainous terrain from Burma to China; and in the Northwest Service Command the Alcan Highway extended 1500 miles from southwestern Canada to Alaska. In Korea truck routes seldom exceeded 50 miles in length.

TABLE 12

NET FUEL SAVINGS
(For 2 million men overseas)

Item	Fuel saved, tons/year
Field kitchens	65,230
Bakery companies	8,190
Refrigeration companies	10,600[a]
Refrigerated warehouses	12,700[b]
Total for irradiated foods	96,720[c]
Preparation of freeze-dehydrated food	–5,080[d]
Total for freeze-dehydrated foods	91,640[e]

[a]Refrigerating equipment only.

[b]Refrigerating equipment only. All electricity generation is assumed to be for refrigeration purposes.

[c]Fuel for electricity for truck shops is less than 0.5 percent of this total.

[d]Fuel consumed in heating of water for freeze-dehydrated foods.

[e]Corresponds to 250 tons/day and is not sensitive to the assumed percentage of men who may eat freeze-dehydrated food regularly. For example, 50 percent freeze-dehydrated food in a theater yields 96,720 – 10,160 = 86,560 tons/year, which corresponds to 237 tons/day.

In this study fuel for refrigeration, field kitchens, mobile bakeries, and water supply points is assumed to be required 500 miles from the supply source. The distance and tonnage (Table 12) are therefore fixed, and the necessary network of adequate roads is assumed to allow the passage of 2½-ton trucks with payloads up to 5 tons.

The fuel load is assumed to be carried by LTCs. Each company has 5 officers and 131 enlisted men (augmented by 30 additional enlisted men to provide 2 drivers per truck and thus permit 20 hr of operation per day). An LTC is equipped with 63 2½-ton cargo trucks. Eighty-three percent of these trucks are assumed to be available, i.e., 17 percent are continually in maintenance.[51] The LTC is used in this section of the study as the basis for estimating the requirements for highway transport.

To estimate LTC requirements for this type of sustained operation, the following formula is used.[44]

$$\text{Companies required} = \frac{\text{daily tonnage} \times \text{operating turnaround time}}{\text{payload} \times \text{availability} \times \text{operating day}}$$

In this formula "operating turnaround time" in hours is computed as follows:

$$\text{Operating turnaround time} = \frac{\text{round-trip mileage}}{\text{rate of movement}} + \text{loading and unloading time}$$

Substituting estimates into the foregoing formula, the following operating turnaround time may be obtained:

$$\text{Operating turnaround time} = (1000/10) + 2.5 = 102.5 \text{ hr}$$

For bulk fuel the cargo limit per truck is 14 55-gal drums, which is $(14 \times 55 \times 7.0)/2000 = 2.70$ tons of bulk fuel per truckload. Thus the number of LTCs is:

$$\text{LTC} = [(\text{tons/day})(102.5)]/(2.7 \times 63 \times 0.83 \times 20) = (\text{tons/day})/27.4 \qquad (1)$$

The tons per day required in Eq. 1 is the total fuel delivered daily to all consumers. This includes 250 tons/day, the demand computed in Table 12, footnote e, plus the fuel for LTCs themselves, and the fuel for all the support elements of all LTCs, which include men, trucks, and equipment for maintenance, security, and road repair.

The consumption of fuel by LTCs may be estimated by assuming that each truck not in a maintenance shop is driven 20,000 miles/year at an average fuel-consumption rate of 5 miles/gal. Thus fuel for each LTC is consumed at the following rate:

$$(20{,}000 \times 63 \times 0.83 \times 7.0)/(5 \times 365 \times 2000) = 2.0 \text{ tons/day}$$

The amount of fuel required for support elements of an LTC is more difficult to estimate, but it is taken to be 11 percent of 2.0 tons/day, based on the number of men required to support one LTC.[51]

With these assumptions, Eq. 1 becomes

$$\text{LTC} = [250 + (2.0 + 0.22)\text{LTC}]/27.4 \qquad (2)$$

Solving Eq. 2 gives 10 LTCs required to deliver 250 tons/day to field kitchens, bakeries, refrigeration compressors, and water points, plus 20 tons/day to these truck companies for their own use, and 2 tons/day to the necessary support elements. The total fuel requirement is therefore 99,300 tons/year, all of which must be delivered overseas by ocean-going tankers.

Tankers

In order to estimate tanker requirements, T2 tankers having a payload capacity of 5.9 million gal (20,600 tons) are assumed available (see Table 13).[52]

These tankers have an average speed of 14.5 knots and require about 43 days for a round trip from Galveston, Tex., to Bordeaux, France (8000 naut mi).[53] Thus about 8.5 round trips/year to Europe are possible with these ships. For the fuel load required here only 99,300/20,600 = 4.8 round trips/year are necessary. Thus one T2 tanker can easily handle the present fuel requirements.

TABLE 13

CHARACTERISTICS OF SELECTED MARITIME ADMINISTRATION SHIPS[52]

Type	Design	Capacity	Speed, knots	Engine, hp	Engine type	Fuel capacity, tons	Distance, thous of miles	Breadth, ft	Over-all length, ft
Tanker	T2SEA1	141,000 bbl[a]	14.5	6,000	Turbine-electric	1485	13	68	524
Reefer cargo	R2STAU1	311,000 ft^3	18.5	13,000	Turbine	1512	7	61	455
Dry cargo	EC2SC1	459,000 ft^3	11.0	2,500	Reciprocating steam	1131	9	57	442

[a]One barrel = 42 gal. Thus 141,000 × 42 = 5.9 million gal.

Refrigerated Ships

The elimination of freeze and chill requirements overseas by the substitution of irradiated meats, fruits, and vegetables for ordinary perishables will reduce the need for reefer ships. However, these ships will be replaced by dry-cargo ships of similar capacity and speed (see Table 13) for the transport of irradiated foods. Thus there is little logistical gain other than an increase in capacity per ship. This increased capacity is due to both simpler construction and lack of need for fuel for refrigerant compressors aboard ship.

Dollar Savings

The dollar savings that may be realized from the logistical advantages of using irradiated foods and freeze-dehydrated foods are estimated and summarized in this section. These savings are computed for food service personnel and vehicles, fuel, LTCs, and tankers. Each of these categories has procurement and operating costs plus combat losses. Combat losses that are normally expected but not incurred are legitimate savings and are included. In addition there is the cost difference between shipping by reefer ship and by dry-cargo ship. Unrefrigerated dry cargo costs less because of the lack of necessity of refrigerating large amounts of cargo space. This difference is relatively small but is included in the cost summary.

Personnel. From Table 10 the number of food service personnel saved by the widespread use of freeze-dehydrated foods and irradiated foods overseas is 14,625 + 2130 = 16,755 men. The men assigned to refrigeration companies and refrigerated warehouses are presumably retained in order to transport and store irradiated foods in the same manner as before (but without

refrigeration). Estimates of procurement and operating costs and combat losses for these field-kitchen and bakery personnel are shown in Table 14.[54]

TABLE 14

COSTS OF FIELD-KITCHEN AND BAKERY PERSONNEL
(For 2 million men overseas)

Item	Cost, millions of dollars
Procurement	
16,755 men @$8000	134
Annual operation	
16,755 men @$6000 per year	100
Annual losses	
84 men[a] @$0.5 million[b]	42

[a]Based on a combat-loss rate of 0.5 percent/year.[55]
[b]ORO estimate.

TABLE 15

COSTS OF FIELD-KITCHEN AND BAKERY TRUCKS
(For 2 million men overseas)

Item	Cost, millions of dollars
Procurement	
2925 field-kitchen trucks @$13,000[a]	38.0
315 bakery trucks @$9500[a]	3.0
Annual operation	
3240 trucks @$3800 per year	12.3
Annual losses	
585 field-kitchen trucks[b] @$10,500	6.14
63 bakery trucks[b] @$7000	0.44

[a]Based on $7000 for 2½-ton trucks.[51] It costs 50 percent more to outfit 2925 of them as kitchens (ORO estimate), plus $2500 per truck for spare parts and equipment to maintain both the field-kitchen and bakery trucks.[47]
[b]Based on a combat-loss rate of 20 percent/year.[55]

Trucks. From Table 10 the number of trucks associated with field kitchens and bakery companies is 2925 + 315 = 3240 trucks. Presumably the trucks used by refrigeration companies are retained for use in hauling irradiated perishables but without the need for cooling. Estimates of procurement and operating costs and combat losses for kitchen and bakery trucks are shown in Table 15.

Fuel. From Eq. 2 the amount of fuel saved by the widespread use of freeze-dehydrated foods and irradiated foods overseas is about 99,300 tons/year. At a delivered overseas price of 20 cents/gal ($57 per ton) the

saving is $5.7 million per year. To this should be added 10 percent for the necessary lubricants and greases.[49] Thus the total fuel saving is about $6.24 million/year.

LTCs. Another major item of logistical cost is the number of LTCs required to haul all the fuel for cooking, heating, and vehicles. Estimates of procurement and operating costs and combat losses for one such company are given in Table 16. From Eq. 2 it was determined that 10 such companies were required. Thus in this study the costs per company must be multiplied by 10 to obtain the total dollar savings from LTCs.

TABLE 16

LTC COSTS

Item	Cost, millions of dollars
Procurement	
166 men @ $6000[54]	1.00
63 trucks	0.60[51]
18 men[a] @ $6000	0.11
Support equipment	0.40[51]
Total	2.11
Annual operation	
166 men @ $6000 per year[54]	1.00
63 trucks	0.24[51]
18 men[a] @ $6000 per year	0.11
Support equipment	0.16[b]
Total	1.51
Annual losses	
4 men[c] @ $0.5 million	2.00
Equipment	0.20[d]
Total	2.20

[a]For maintenance, security, and road repair.[54]
[b]Based on 0.40 × (0.24/0.60) = 0.16.
[c]Based on 184 men at 2 percent/year.[54]
[d]Based on $0.60 + $0.40 million at 20 percent/year.[54]

Tankers. Estimates of the procurement and annual operating costs of a T2 tanker are given in Table 17. In this study only one such tanker is required to haul fuel overseas in order to deliver the amount needed.

Nonrefrigerated Shipping. For (3/4) × 0.44 lb/man/day of perishables and 1.05 million men who may receive perishables regularly, the annual refrigerated tonnage required in this study is

$$(3/4) \times 0.44 \times 1.05 \times [(10^6 \times 365)/2000] = 6.3 \times 10^4 \text{ tons/year}$$

The cost difference between refrigerated and nonrefrigerated ocean shipping is about $14.50 per ton[56] (Brooklyn to Bremen, a 7000-naut-mi round trip). Thus the annual saving is about $0.915 million/year, which is small compared with other logistical factors.

For an assumed refrigerated-cargo density equal to 60 lb/ft^3 the annual refrigerated capacity is 2.1×10^6 ft^3/year. The corresponding ship requirements are shown in Table 18. For either reefer (conventional perishables) or dry-cargo ships (irradiated foods) the annual tonnage requirement of this study is satisfied by a single ship.

TABLE 17

COSTS OF A T2 TANKER

Item	Cost, millions of dollars
Procurement	
Construction	6.25[53]
Equipment and staff	3.17[53]
Cargo	1.18[a]
Annual operation	0.94[b]

[a]Based on 5.9 million gal of fuel at 20 cents/gal.
[b]Based on 10 percent/year of \$6.25 + 3.17 million (ORO estimate).

TABLE 18

SHIP REQUIREMENTS
(For 2 million men overseas)

Item	Ship type: Reefer (conventional perishables)	Ship type: Dry cargo (irradiated foods)
	Requirements	
Design	R2	EC2
Speed, knots	18.5	11.0
Capacity, thous of ft^3	311	459
Round-trip time (7000 naut mi), days[a]	36	46.5
Round trips available/ship/year[b]	10	7
Round trips required/ship/year[c]	7	5
Ships required (no losses)	1	1

[a]Travel time + 20 days = $[7000/(24 \times \text{speed})] + 20$.
[b]365 days/round-trip time.
[c]$(2.1 \times 10^6\ ft^3)$/ship capacity.

Summary of Dollar Savings. The major items discussed above are summarized in Table 19. Using freeze-dehydrated foods and irradiated foods for 1 year overseas in a theater of operations containing 2 million men leads to an estimated saving of \$412 million. This saving corresponds to 56 cents/man/day for the first year. If this feeding system is used for 2 years or more,

each additional year adds about \$135 million (Table 19, footnote a). In terms of cost per man per day this is

$$(135 \times 10^6 \times 10^2)/(2 \times 10^6 \times 365) = 18.5 \text{ cents/man/day}$$

that may be added to the first year's savings.

TABLE 19

SUMMARY OF DOLLAR SAVINGS

(For 2 million men overseas)

Item	Quantity	Savings, millions of dollars		
		Procurement	Operating, per year	Total for 1 year
Men				
Original number	16,755	134	100	276
Losses	84	42.0	—	—
Trucks				
Original number	3,240	41.0	12.3	59.9
Losses	648	6.58	—	—
Fuel	99,300	6.24	—	6.24
LTCs				
Original number	10	21.1	15.1	58.2
Losses	—	22.0	—	—
Tankers	1	9.42	0.942	10.4
Dry-cargo shipping	—	—	0.915	0.915
Total	—	—	129[a]	412[b]

[a]Excludes fuel. Total saving in annual operating costs, including fuel, is \$135 million per year.

[b]Water cost is not included explicitly because it is small in comparison. For example, 200 million gal/year at \$1 per 1000 gal is \$0.2 million per year.

In Table 19 the major item is food service personnel—which does little more than confirm the contention of QMC officers that this is the chief logistical gain from the introduction of these streamlined feeding systems. At least this confirms their contentions, although the savings in kitchen trucks and LTCs are substantial also.

LIMITED WAR

Food logistics is important not only in a widespread conflict but also in limited wars wherein US forces may have to enter a small theater of operations and fight under adverse conditions of climate, terrain, and guerrilla warfare. Iran, Indochina, and Korea are examples of such areas. Iran is hot and dry and has flat deserts and bare mountains. Indochina is hot and wet and has forests, mountains, and broad river deltas where rice is cultivated. Korea can be cold and wet and has both plains and mountains.

Not only do climate and terrain affect logistical operations but so does the presence of local native guerrilla armies—as the French have experienced in Indochina in recent years. Indeed guerrilla warfare is primarily war on logistics. It is characterized by stealthy attacks against enemy weak points such as poorly defended airstrips, motorized columns, or garrisons. Invariably guerrilla attacks are directed against cargo planes, trucks, or supply dumps and never against well-armed troops or armor. Such covert activity may be limited in flat uncovered areas like Iran, moderately bothersome in Korea, and intense in Indochina, where roads, rail lines, and inland waterways are scarce and unimproved. Each of these important areas is discussed from the point of view of food logistics.

Iran (and other similarly parched areas) is important logistically because availability of water is a serious military problem. Since there are no more than 15 in. of rainfall annually over most of this nation, potable water is scarce almost everywhere except in the region of Teheran and the Caspian Sea.[57] In this complex of mountains and deserts, natural routes of land travel are few and water transportation is important. Because of intense summer heat the daily water requirement of men increases 3 to 5 times that normally needed. A study of water in Iran during July, the hottest month, indicated a barely adequate supply for one US division on defense and an inadequate supply for an offensive operation.[58] Under such conditions freeze-dehydrated foods seem inappropriate, indeed detrimental, to operations if irradiated foods of comparable quality are available.

Experience in WWII desert campaigns in North Africa shows that water denial can be an effective tactic in reducing enemy fighting efficiency. If the objective of US forces in Iran were to push an enemy out of Iran, then that enemy would probably attempt to deny water to those forces. Thus in a hot, dry climate water is specially precious. Because irradiated foods can be precooked ready to eat and require little water for preparation, their use in such a climate seems particularly advantageous.

Iran, because it can be hot, generates an increased requirement for refrigeration for some food items. Refrigeration equipment and the fuel to operate it are an additional logistical burden, so that uncooked, fresh-like irradiated food that does not require refrigeration is also a logistical advantage. Thus irradiated food in both cooked and uncooked forms appears to be advantageous in hot, dry climates.

The summer heat in Iran intensifies food-storage difficulties. Packaged operational rations that normally last 24 months may last only one-third as long under such conditions.[57] Thus if irradiated food is to replace canned food in hot climates, it must have a comparable shelf life under both normal and extreme temperatures.

Another possible location of limited war that may involve US forces is Indochina, with its tropical climate, forested highlands, broad river deltas and mud flats, and extensive rice-paddy cultivation. The forests are difficult to penetrate and afford excellent concealment. Also dense thickets of mangrove trees grow near the mouths of the larger rivers. The rice paddies with their system of levees and canals and the practice of flooding these fields during the growing season all present particularly severe barriers to surface movement of US troops and vehicles. Communist forces in that area are experienced

at cross-country movement under such conditions. Although their logistical system is primitive in the sense that they use few vehicles, they can rely on hordes of porters. These coolies are expendable and are far less an encumbrance than motorized columns. Coolies use trails and are remarkably invulnerable to air superiority. Moreover their food requirements are minimal—viz., local rice and fish supplemented with coconuts, yams, and tea.

Since guerrilla forces specialize in attacking an opponent's weak points, poorly guarded supply dumps of rations with their necessary trucks and cooking fuel are prime targets. In a hot climate like Indochina there is little requirement for hot meals so that cooking fuel is not crucial—particularly if irradiated food is available. Trucks are crucial, however, and truck convoys are highly vulnerable on the poor roads of this area. Thus guerrillas may force US units to become isolated from supplies except by aerial resupply. For example, the French in Indochina got water to their isolated troops by airdropping it in the form of large blocks of ice. Thus water can be an extra logistical burden.

Under such conditions where a minimal logistical system is required, freeze-dehydrated food with its extra water, stove, and heating-fuel requirements appears to be undesirable. Instead precooked irradiated food will be important both logistically and for troop mobility. As a result irradiated ready-to-eat meals should find wide use with US forces in Indochina.

In this tropical climate with its high temperatures, refrigeration is normally necessary for some food items. Irradiated fresh-like foods will alleviate this problem, provided that the packaging materials will remain intact and thus maintain sterility of the food under the hot, humid conditions.

In a climate that can be cold like Korea, and particularly with the static military situation that exists there today, there is a continuing requirement for hot meals as often as possible, not only for warmth but for morale as well. Thus in the 1965–1975 time frame uncooked, irradiated, fresh-like food items and freeze-dehydrated quick-serve meals served hot seem suitable as a contribution to a simpler supply system that replaces refrigeration equipment and field kitchens. Also in Korea, as in other climates, precooked, irradiated, ready-to-eat foods should be useful for patrols and outposts that normally do not receive hot meals.

Today US troops in Korea get frozen meat that is shipped from the US to Japan and airlifted from there to Korea. This logistical operation requires reefer ships and then prompt airlift to the users. There is often considerable spoilage by the time such meat gets to the troops. Irradiated meat should eliminate this spoilage and at the same time obviate the need for expensive refrigerated cargo space. A similar situation arose during the Lebanon operation (1958) when the Navy attempted to ship refrigerated perishables directly from Norfolk, Va., 6000 miles to Lebanon. The results were poor, with spoilage in some cases approaching 100 percent. The benefits of irradiated foods are again clear: not only is the expensive refrigeration eliminated but also the severe spoilage.

At bases more remote and colder than Korea, such as Thule, Greenland, or McMurdo Sound, Antarctica, where nuclear reactors may supply adequate base power and combat is nonexistent, morale is the basic problem—as it also is on nuclear submarines. Here again uncooked, irradiated, fresh-like food

should be an advantage. Such food can be shipped without refrigeration and spoilage and can be stored for use throughout long periods when resupply is denied. Personnel at polar bases and on nuclear submarines have no requirement for quick-serve or ready-to-eat meals or for anything but the "comforts of home" in order to keep morale high.

Another problem connected with refrigeration today is the continual shortage of refrigeration-equipment mechanics overseas, particularly in Japan, Korea, and Alaska. Coupled with this is the shortage of refrigerated storage space in the US. Both of these difficulties may be alleviated by the use of irradiated fresh-like meats, fruits, and vegetables.

COST ANALYSIS

INTRODUCTION

This section of the study is concerned with the dollar cost of providing the armed forces with food processed by ionizing radiation and by freeze-dehydration. Although the means for large-scale commercial production are not yet available, for the purposes of this study it is assumed that production facilities could be available by the 1965–1975 time frame. Consideration of the use of irradiation as a method of preserving food goes back approximately a decade, and many estimates of the cost of radiation processing can be found in the literature. Freeze-dehydration, which has a much longer history as a technique for the preservation of pharmaceuticals and antibiotics, has recently come into prominence as a promising method of food preservation, and a considerable amount of experimentation and some pilot-plant production has been carried out by industrial food processors.

The material that follows discusses the processing, packaging, and transportation costs associated with food processed by the techniques mentioned. The data on processing and packaging were obtained from available literature and from direct contact with machine manufacturers, food processors, and other sources.

As with any food-preservation technique, the processing cost per pound for both freeze-dehydration and irradiation will vary with the product processed. Similarly not all food products will lend themselves readily to processing by these techniques. It is assumed, however, that cost estimates for processing meats will provide a useful basis for evaluating both processes for the preservation of food for military consumption. This section therefore discusses the cost of supplying the armed forces with irradiated meats and compares these costs with those of supplying meats processed by other methods, including freeze-dehydration.

In response to requirements set forth in CDOG,[59] QMC is developing packaged rations in which component food items are assembled in quantities appropriate for feeding specified numbers of meals. The transition from the present bulk system of food supply to a future system of unitized meals is already under way, as evidenced by the existing practice of procuring selected items of the B ration in multimeal modules.[60] In accordance with this trend, this analysis of the cost of processing, packaging, and transporting irradiated and freeze-dehydrated food is based on the future use of unitized meals. It is assumed that preprocessing costs—the cost of cutting and trimming meat to package size—will be essentially the same whatever processing technique is used; thus

these costs are not examined. For the purposes of this study, costs are based on a radiation-sterilization dose of 4.5 Mrad.

PROCESSING COSTS

The following discussion develops the cost per pound to process meat by ionizing radiation—using both electron accelerators and radionuclides—and by freeze-dehydration. The methods of processing are described briefly, but more detailed descriptions are published elsewhere.[61] For each method initial costs are first determined, and to these are added annual operating costs. The cost per pound of processed product is then determined over a period of 10 years by dividing the cumulative annual production into the cumulative annual total cost.

Electron Accelerators

Electron accelerators convert conventional electric-line power to electron power. The electrons, which are formed into a beam, are accelerated to a high energy, and this beam of high-energy electrons is directed at the material to be irradiated. The thickness of material that can be penetrated is directly proportional to the energy of the beam and is inversely proportional to the density of the material. For meat, which for simplicity can be taken to have a density of one, a 1-mev beam can penetrate to a depth of approximately 0.5 cm; a 2-mev beam, approximately 1 cm; and so on linearly. The number of electrons in the beam determines the length of time that the product to be irradiated must be exposed to the beam to achieve the desired radiation dose. Thus with a fixed voltage, a product of appropriate thickness, and a fixed dose requirement, the amount of product processed per unit time is a function of the kilowatt power of the accelerator.

At the present state of the art, high voltage and high power are competing parameters in the design of electron accelerators. High-voltage accelerators in use today in laboratories and industrial plants throughout the country are generally low powered. Although such machines would be capable of deep penetration of meat, they do not appear suitable for this application because voltages above about 10 mev may induce radioactivity in the product.[2-4] Furthermore even in the absence of this hazard such machines do not appear attractive for processing meat because their high operating and maintenance costs would result in high processing costs.

Since there has heretofore been little requirement for them, very few low-voltage accelerators with high power exist. Most low-energy accelerators in operation today are also low powered.[62,63] Although such machines could be safely employed in the irradiation of meat of appropriate thickness and would be relatively inexpensive to operate and maintain, they would not provide a suitable means for the radiation sterilization of meat because of their inherent slow processing rate. For these reasons this cost analysis is oriented in terms of low-energy accelerators over a spectrum of power ratings.

Initial Cost of Electron Accelerators. The initial cost of electron accelerators is the sum of the purchase price of the accelerator, freight charges for

delivery of the accelerator from manufacturer to processor, and certain installation costs. These costs are discussed briefly in the next three paragraphs.

Purchase price of accelerators. On the basis of prices available in the literature and quoted or estimated by manufacturers, an earlier study reported the purchase price of accelerators in thousands of dollars per kilowatt as a function of the rated power output for accelerators up to approximately 50 kw.[64] More recent data indicate no substantial change in these prices, but permit extrapolation of purchase-price estimates for accelerators of even higher outputs.[65,66] These data were used to construct Fig. 3, which shows the estimated purchase price for machines with power ratings up to 100 kw. Because of price variations for similar machines, the curve is in the form of a band embracing the highest and lowest prices. As the figure indicates, the cost per kilowatt of output power decreases with the increase in the power rating of the accelerator. The median cost declines from approximately $13,000 per kilowatt for a 10-kw machine to approximately $2000 per kilowatt for a 100-kw machine.

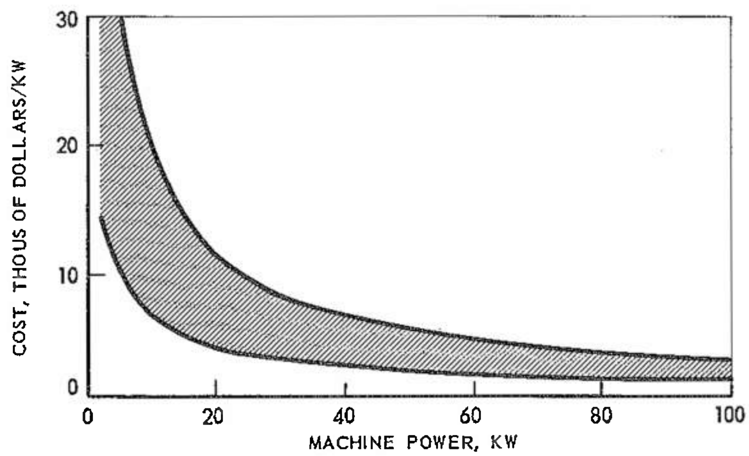

Fig. 3—Estimated Purchase Price of Accelerators

To facilitate comparison with other processing techniques, the kilowatt power requirements for several rates of production of processed meat were calculated, as described in Appendix B. The results of these calculations are shown in Table 20.

Table 21 lists the maximum and minimum procurement costs for electron accelerators, based on cost per kilowatt taken from Fig. 3, having the power ratings listed in Table 20.

Transportation charges. The cost of delivering the accelerator from the manufacturer to the point of use was assumed to be $150 per kilowatt.

Installation costs. The costs of building space, primary shielding, cooling and ventilating machinery, and other equipment are shown in Fig. 4. Installation costs in the literature and quoted or estimated by machine manufacturers for equivalent machines varied somewhat, and maximum and minimum costs are embraced in the curve. As the figure indicates, installation costs per kilowatt of output decrease with increased accelerator size.

Total initial cost of electron accelerators. The sum of the purchase price plus the transportation and installation costs for five accelerators having the production-rate capacity listed in Table 20 is shown in Table 22.

TABLE 20

POWER REQUIREMENTS FOR ACCELERATORS WITH VARIOUS PRODUCTION RATES

Production rate, lb/hr	Power requirement, kw
1,000	9.5
2,000	19.0
3,000	28.5
6,000	57.0
10,000	95.0

TABLE 21

PROCUREMENT COSTS FOR ACCELERATORS WITH VARIOUS PRODUCTION RATES

Production rate, lb/hr	Cost, thous of dollars	
	Minimum	Maximum
1,000	66	190
2,000	76	218
3,000	85	256
6,000	88	283
10,000	95	285

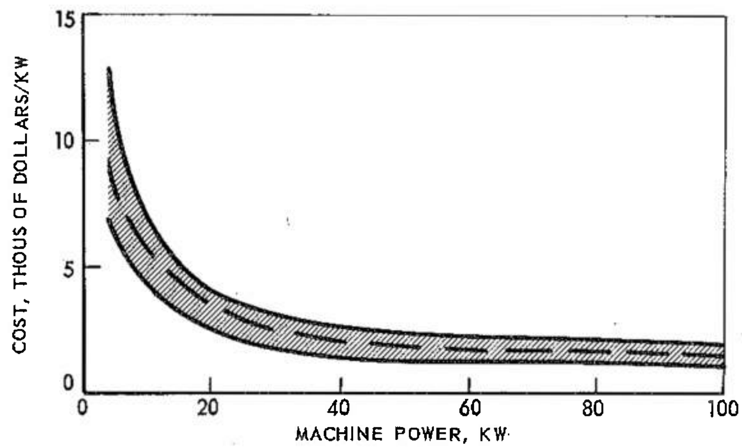

Fig. 4—Installation Price of Accelerators

Annual Operating Costs. Annual operating costs are taken to be the sum of the direct labor costs for the technicians required to operate and maintain the accelerator, overhead, source replacement, parts, and utility costs. Table 23 lists these costs for accelerators having the five production rates listed in Table 20. The number of technicians required for the safe operation and maintenance of the accelerator is assumed to increase with accelerator size. Similarly it is assumed that the cost of replacing vacuum tubes and other source materials is more for the higher-powered accelerators.

Processing Costs. To determine the processing cost in cents per pound, the initial cost, plus the cumulative annual operating cost, was compared with cumulative annual output for accelerators having various production rates. The results of these calculations are shown in Fig. 5. The costs for the first and second years are relatively high because of the high initial cost, but they

decrease rapidly over the increasing total production. It can be seen also that processing cost decreases as the accelerator power increases. For a 100-kw accelerator the processing cost decreases to about 0.5 cent/lb after the third year.

TABLE 22

TOTAL INITIAL COST OF ACCELERATORS WITH VARIOUS PRODUCTION RATES

Production rate, lb/hr	Cost, thous of dollars	
	Minimum	Maximum
1,000	121	244
2,000	145	288
3,000	160	331
6,000	209	405
10,000	252	442

TABLE 23

ANNUAL OPERATING COSTS FOR ACCELERATORS[a] WITH VARIOUS PRODUCTION RATES

Production rate, lb/hr	Men	Cost, thous of dollars				
		Direct[b] labor	Overhead[c]	Source[d] replacement	Parts[e] and utilities	Total
1,000	2	42	42	28	14	126
2,000	2	42	42	35	20	139
3,000	3	63	63	42	27	195
6,000	3	63	63	49	47	222
10,000	4	84	84	70	74	312

[a]Based on 7000 hr per year of operation.
[b]Based on $3.00 per man-hour of labor.
[c]100 percent of direct labor cost.
[d]Includes vacuum-tube replacement and other source materials, estimated at $4, $5, $6, $7, and $10 per hour of operation, respectively.
[e]Parts estimated at $1 per hour of operation and utilities at 1.5 cents/kw-hr with a 15 percent power-conversion efficiency.

Gamma Radiation

At present Co^{60} is the most attractive source of gamma radiation for food processing because techniques for its fabrication are well understood, it can be made in large quantities, it has a long half-life (5.3 years), and the energy of its rays (1.1 and 1.3 mev) is below that known to induce radioactivity in food. In practical use gamma rays differ from the high-energy electrons produced by an accelerator in that their omnidirectional radiation cannot be bent or focused and they cannot be switched on and off. As a result the shielding

requirements are more severe than for electron accelerators, proper orientation of the source to the product introduces special problems, and it is difficult to shut down operations for maintenance or repairs of the production line. On the other hand gamma rays are more penetrating and permit the processing of thicker pieces of meat. Maintenance work on the source itself is reduced simply to replacing the spent cobalt. Estimates of the cost of producing Co^{60} range from 20 cents to $1 per curie. For the purposes of this study, however, lower Co^{60} costs are included, for it appears possible for the future cost to drop as low as 1 cent/curie.

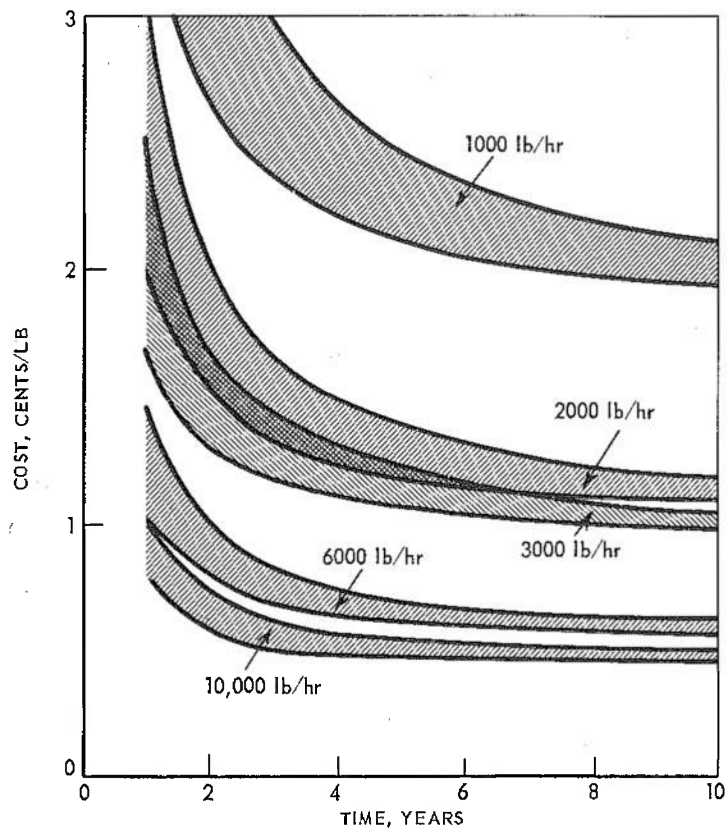

Fig. 5—Processing Costs as a Function of Time for Accelerators Having Various Production Rates

Source-Material Requirements. To compare Co^{60} with electron accelerators, the amount of Co^{60} required for the same production rates was determined (see Appendix B). These quantities are listed in Table 24.

Cost of Source Preparation. The fabrication and encapsulation of Co^{60} is at present a batch process, and there is no actual experience in the preparation of megacurie sources. According to Arthur D. Little, Inc., the indications are that source-preparation costs of 5 cents/curie for Co^{60} are feasible.[64]

Transportation Costs. Freight charges at the rate of 1 cent/curie are assumed to cover the cost of transportation of the source material from the point of processing to the point of use.

Facility Costs. The costs of building space, primary shielding, and cooling and ventilation equipment were estimated for various production-rate facilities and are listed in Table 25.

TABLE 24

Co^{60} REQUIREMENTS FOR VARIOUS PRODUCTION RATES

Production rate, lb/hr	Co^{60} requirement, megacuries
1,000	1.92
2,000	3.84
3,000	5.73
6,000	11.50
10,000	19.20

TABLE 25

Co^{60} FACILITY COSTS

Production rate, lb/hr	Cost, thous of dollars
1,000	24
2,000	48
3,000	71
6,000	143
10,000	239

Total Initial Costs. Total initial costs of a Co^{60} food-irradiation facility consist of the delivered cost of the source material plus the initial cost of the facility. Total initial costs for various Co^{60} prices are shown in Table 26.

TABLE 26

TOTAL Co^{60} INITIAL COSTS

Production rate, lb/hr	Cost of Co^{60}, cents/curie			
	1	10	20	50
	Cost, thous of dollars			
1,000	158	331	523	1,100
2,000	317	662	1050	2,200
3,000	472	988	1560	3,280
6,000	945	1980	3120	6,560
10,000	1580	3310	5230	11,000

Annual Operating Costs of a Gamma-Irradiation Facility. Cost of source replenishment. Were a Co^{60} source in one piece, total replacement would be required when source activity decayed below the desired level. Segmentation of the source, on the other hand, permits replacement of segments individually in order to maintain a specified level of activity. It is assumed that segmentation permits annual replacement of 12.5 percent of the Co^{60} requirement.[64]

Labor, overhead, parts, and utilities. Personnel requirements for operating and maintaining the processing facility and the cost per operating hour for utilities and miscellaneous parts are assumed to increase with the size of the source. Labor costs are assumed to be $3.00 per man-hour, and a facility is assumed to operate 7000 hr/year. Overhead is taken to be 100 percent of the direct labor costs.

Total annual operating costs. Total annual operating costs using Co^{60} are listed in Table 27.

TABLE 27

TOTAL ANNUAL OPERATING COSTS FOR Co^{60} FOR VARIOUS PRODUCTION RATES

Production rate, lb/hr	Cost of Co^{60}, cents/curie			
	1	10	20	50
	Cost, thous of dollars			
1,000	145	166	190	262
2,000	162	205	253	397
3,000	222	286	358	587
6,000	272	471	544	1000
10,000	383	599	839	1560

Co^{60} Processing Costs. Processing costs per pound were calculated over a period of 10 years by dividing the cumulative output of processed meat into the cumulative total cost of operations; i.e., the initial cost plus multiples of the annual operating cost. The results of these calculations are shown on Figs. 6 to 9. Processing cost decreases as production rate increases, but it is not extremely sensitive to the price of the source material. Despite the fact that the highest and lowest costs per curie of Co^{60} differ by a factor of 50, processing costs differ only by a factor of about 3. Processing cost after 10 years of operation decreases to less than 4 cents/lb at 50 cents/curie at a production rate of 6000 lb/hr, as indicated in Fig. 6. At 20 cents/curie, which is approximately the present Atomic Energy Commission price,[67] the corresponding processing costs about 2 cents/lb (see Fig. 7).

Freeze-Dehydration

In this process the product is first quick frozen, which minimizes cell damage and facilitates later rehydration. The product is then placed on trays for introduction into a cabinet, where the ice is sublimed under low heat and vacuum leaving a porous, dehydrated product of approximately the original dimensions in which the water content has been reduced to approximately 2 percent by weight. As a method of preserving meat, the process is attractive to military planners because this product also could have a long shelf-life without refrigeration and would weigh approximately 50 percent less than in its natural state.* On the other hand the process as currently developed has certain limitations. Because the product dehydrates from the surface to the center and the dehydrated surface acts as an insulator, limitations are imposed on the thickness

*The water content of meat varies with the specie of the animal and increases with the degree of leanness. For example, the water content by weight of fat pork is approximately 35 percent; for lean beef, approximately 65 percent. Of course drying time and weight loss are both a function of the water content of the raw product.

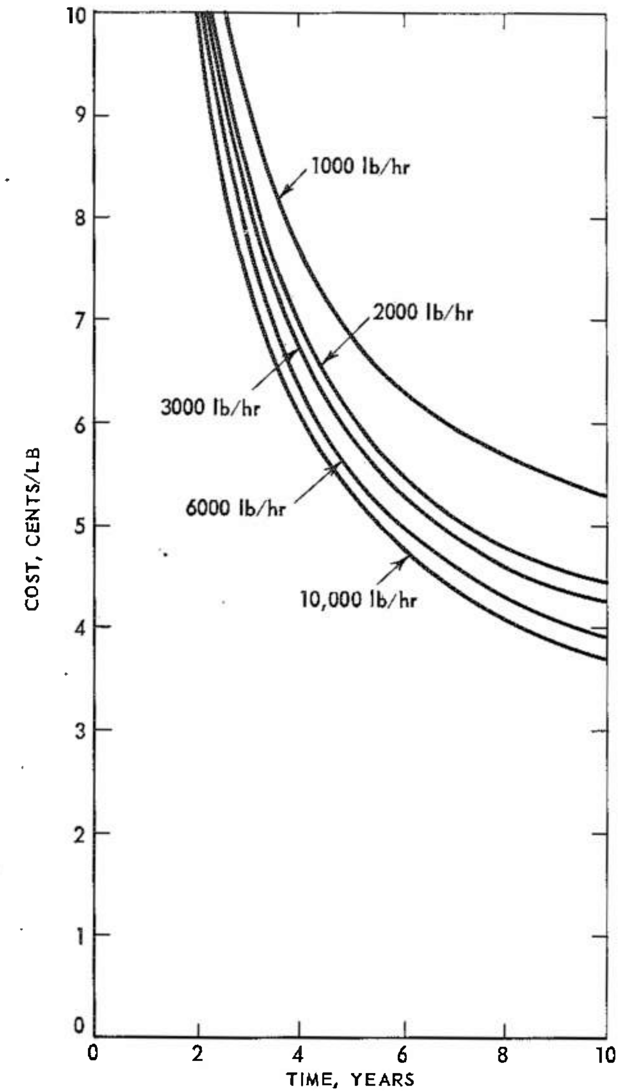

Fig. 6—Processing Costs as a Function of Time for Co^{60} at 50 Cents/Curie for Various Production Rates

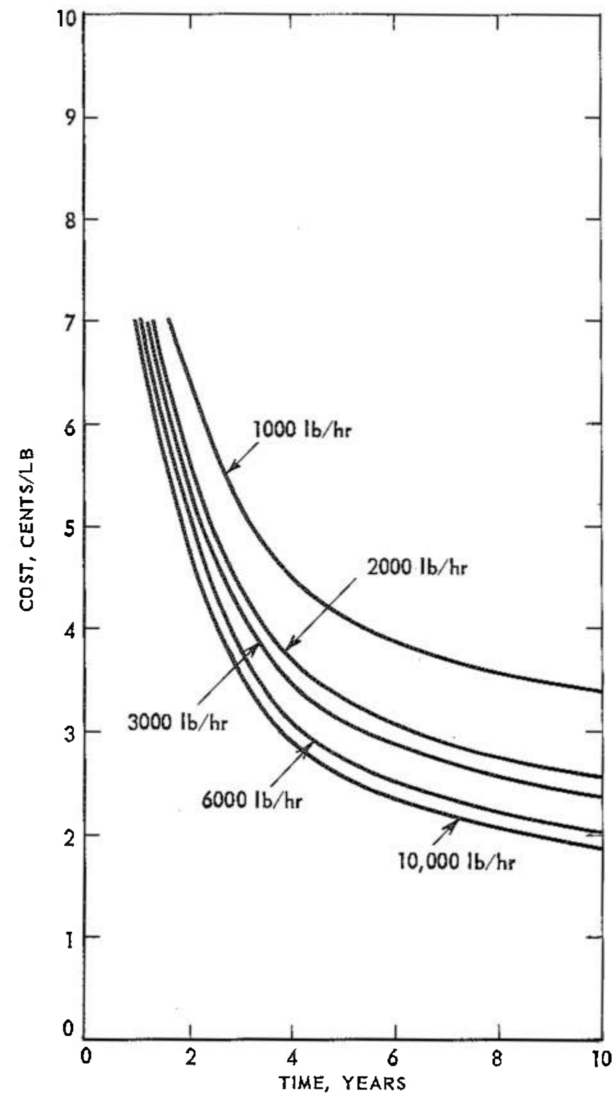

Fig. 7—Processing Costs as a Function of Time for Co^{60} at 20 Cents/Curie for Various Production Rates

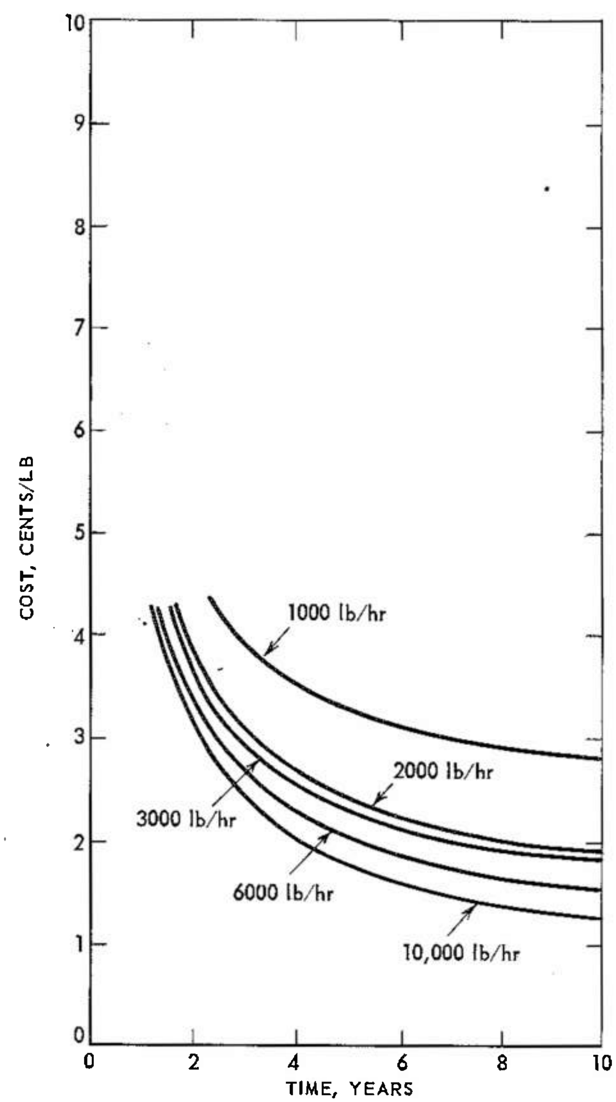

Fig. 8—Processing Costs as a Function of Time for Co^{60} at 10 Cents/Curie for Various Production Rates

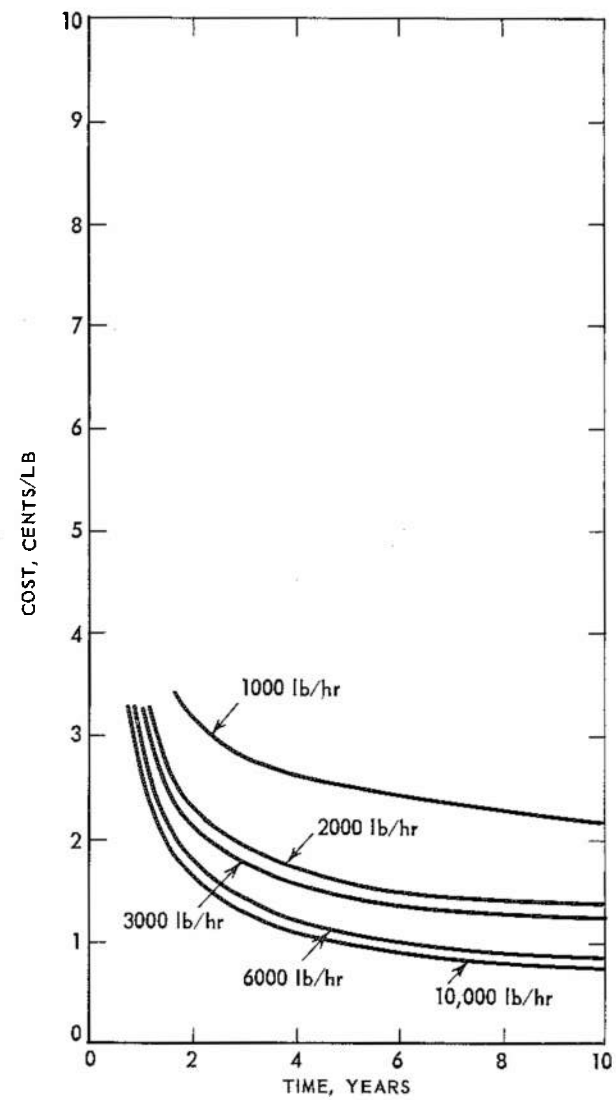

Fig. 9—Processing Costs as a Function of Time for Co^{60} at 1 Cent/Curie for Various Production Rates

of the product that can be processed. In the case of meat this limitation is approximately $\frac{5}{8}$ to $\frac{3}{4}$ in.[68,69] A second limitation is that the process does not lend itself readily to a conveyer-belt type of operation. Although continuous processing may be technologically possible, requirements for atmosphere-to-vacuum seal on entering and leaving the dryer, residence time in the dryer, and variations in the operating pressure during the drying cycle have been shown to result in higher capital-investment costs and more difficult equipment-design problems than those for a batch-type process.[70]

Almost all freeze-drying equipment that has been sold consists of small cabinets used for the processing of pharmaceuticals and similar products. It was estimated in 1959 that the total of all such equipment installed in the US had a capacity, in terms of water vapor removed, of less than 1000 lb/hr.[70] Extrapolation of the operating cost of this equipment to large-scale processing of meat would have little if any meaning. More recently certain food processors have had larger cabinets built and some "custom" processing of food has taken place.[68,69] Such food processors are reluctant to indicate costs, both because they are not representative of full-scale commercial operations and because, in the highly competitive food-processing field, this information is proprietary and is closely held. Cost data, therefore, were sought from food-machinery manufacturers.

TABLE 28

INITIAL AND OPERATING COSTS FOR FREEZE-DEHYDRATION

Item	No. of drying units		
	One	Two	Four
	Cost, dollars		
Initial cost			
Freeze-dry system	59,900	91,800	179,000
Installation and freight	20,000	35,000	70,000
Total	79,900	126,800	249,000
Annual operating cost			
Utilities[a]	4,400	6,000	8,800
Labor and overhead[b]	24,000	24,000	24,000
Total	28,800	30,000	32,800

[a]Power cost at 55 cents, 75 cents, and $1.10 per hour for 1, 2, and 4 units, respectively.

[b]One man at $3.00 per hour.

By the use of multiple drying units and a "staggered-batch" mode of operation, many of the benefits of production-line techniques can be realized. Common vacuum, heating, and refrigerating systems can be shared by all dryers, and both preprocessing and packaging operations can be systematized. One manufacturer of food machinery has devised such a system, and Table 28 is based on cost estimates supplied by this manufacturer.[71]

Figure 10 shows the cost per pound (wet weight) for one, two, and four drying units over a 10-year period of operation, assuming 7000 hr of operation per year, a capacity of 1200 lb of raw product per unit, and a drying time of 18 hr/batch. In Fig. 10 processing cost after 10 years decreases from about 7 cents/lb for one drying unit to less than 3 cents/lb for four units. The cost advantage of the staggered-batch concept is evident.

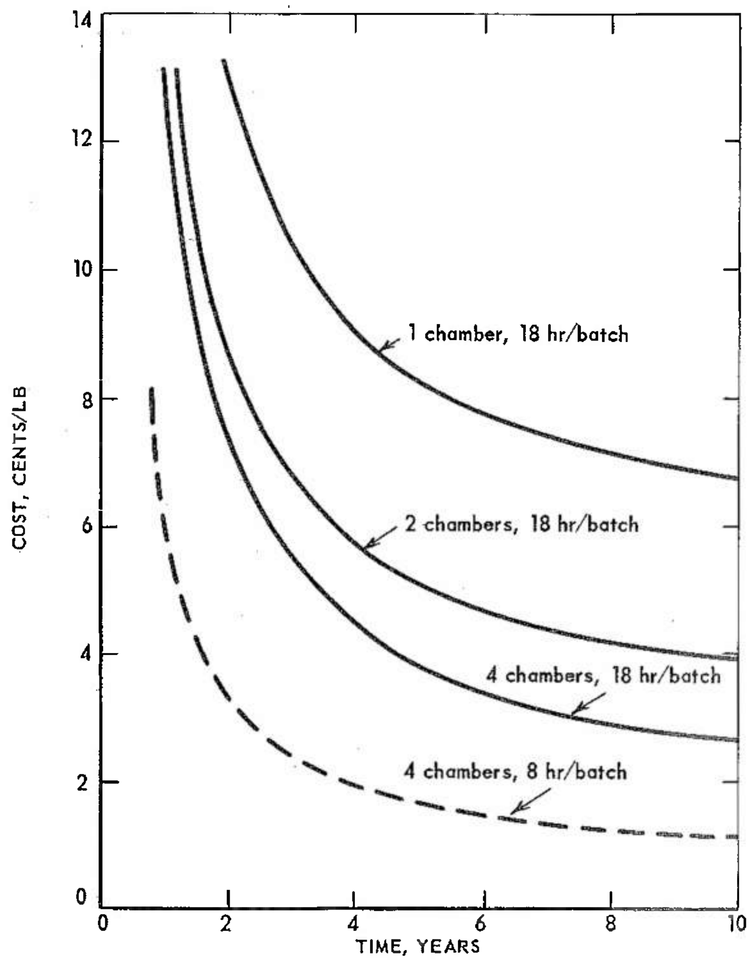

Fig. 10—Processing Costs as a Function of Time for Freeze-Dehydration for Various Production Rates

The drying units discussed above rely on the circulation of warm liquid through hollow shelves on which product-loaded trays rest. A dryer of European design increases heat transfer to the product by lightly compressing the product between movable heated shelves. Depending on the product a reduction in drying time of one-half to two-thirds over conventional dryers is claimed.[72] On the assumption that drying time might be reduced at no increase in capital or operating costs, processing costs on the basis of an 8-hr drying cycle per batch are also plotted in Fig. 10 (dotted line).

PACKAGING COSTS

Although the development of flexible packaging materials is still undergoing research, it is assumed for purposes of this analysis that the types of materials best suited at the present time will be adequately developed for this purpose by 1965. The cost of packaging irradiated and freeze-dehydrated foods is discussed below.

Tin-plate cans of sizes now used for thermal processing of foods could be used for packaging irradiated foods prior to processing and would be suitable for freeze-dehydrated foods; however, many such packages would be too large for irradiation in electron accelerators of less than 10 mev. In order to estimate the cost of small cans that might be designed for use in irradiation processing, the costs of present-day tin-plate cans of several sizes[73] were divided by their respective areas. This analysis revealed a tin-plate–can cost of approximately 8.8 cents/ft^2. Inasmuch as aluminum manufacturers are offering aluminum sheet to can manufacturers at about the same price as tin plate and are vigorously seeking a larger share of the can market,[74] it can be assumed that this price is also representative of the cost of aluminum cans.

Of the flexible wraps tested so far, one of the most satisfactory has been found to be Mylar. Although this plastic film loses strength during storage, it imparts practically no odor or taste to food, is resistant to stress cracking, and is otherwise attractive.[12] The price of Mylar in sheets 0.003 in. thick is approximately 8.5 cents/ft^2.[75]

In terms of enclosing equal volume therefore, it appears that there may be no significant difference in the cost of rigid and plastic packaging materials.

Processing and packaging techniques differ for irradiated and freeze-dehydrated foods. Irradiated food must be packaged prior to processing to assure that sterilization is maintained. Freeze-dehydration, on the other hand, involves removal of moisture so that packaging must follow processing. As a result packaging for the 25-in-1 and 6-in-1 rations could be less expensive for freeze-dehydrated than for irradiated meat processed in an electron accelerator. Limitations on the thickness of the meat that can be processed would require steaks, chops, and other large pieces of meat to be packaged individually or in small numbers prior to processing, whereas freeze-dried pieces of meat could be packaged after processing in modules of 6 or 25. Although the volume to be packaged is the same, the total surface area to be covered is larger in the case of individually wrapped portions.

Table 29 illustrates this relation for packaging in plastic wrap of 4- by 4- by $\frac{3}{4}$-in. pieces of meat assumed to weigh $\frac{1}{2}$ lb. In the "Irradiation" column, it is assumed that each piece is individually wrapped; in the "Freeze-dehydration" column, that the total number of pieces is wrapped in one package. Sufficient overlap for seaming is allowed.

TRANSPORTATION COSTS

Domestic transportation costs per ton-mile for nonperishable subsistence items purchased for military consumption are approximately 28 percent less than those for perishable items.[76] Similarly the ocean shipping rates per

measurement ton are less for general than for refrigerated cargo.[77] It is immediately apparent, therefore, that freeze-dehydrated and irradiated meat can be transported at less cost than chilled or frozen meat.* Furthermore the fact that domestic freight rates are based on weight implies that, per unit volume, freeze-dehydrated meat, because of its lighter weight, could be transported more cheaply than other types of meat, including canned. Theoretical savings of this type are illustrated in Table 30,[78,79] which compares the estimated cost of transporting various kinds of meats from Chicago to Southeast Asia.

TABLE 29

COMPARISON OF PACKAGING COSTS FOR IRRADIATED AND FREEZE-DEHYDRATED MEAT

Type of meal	Process	
	Irradiation	Freeze-dehydration
	Cost, cents/lb	
Individual	1.6	1.6
6-in-1	9.6	3.4
25-in-1	40.0	9.0

TABLE 30

COST OF TRANSPORTING MEAT

Type of meat	Weight, lb	Cost, dollars		
		Rail	Ocean	Total
Chilled	100	2.81[a]	2.94[b]	5.75
Canned	100	1.73[c]	1.85[d]	3.58
Irradiated	100	1.73[c]	1.85[d]	3.58
Freeze-dehydrated	Equivalent[e]	0.87[c]	1.85[d]	2.72

[a]Based on carload rate of $2.58 per 100 lb from Chicago to San Francisco, plus estimated 23 cents per 100 lb for en route icing.[78]

[b]Based on $41.20 per measurement ton from the West Coast to Southeast Asia, and an assumed 1600 lb/measurement ton, plus estimated stevedoring cost of $5.80 per measurement ton.[77]

[c]Based on carload rate of $1.73 per 100 lb from Chicago to San Francisco.[79]

[d]Based on $25.60 per measurement ton from the West Coast to Southeast Asia and an assumed 1600 lb/measurement ton, plus estimated stevedoring cost of $4.00 per measurement ton.[77]

[e]Assuming 50 percent reduction in weight, no decrease in volume.

*This would not be true if the appearance of these new "commodities" were followed by the introduction of special (higher) freight rates. In the case of certain freeze-dried items, for example, it is conceivable that their fragile nature would prompt carriers to seek higher rates.

Both freeze-dehydrated and irradiated foods, however, are intended for inclusion in the unitized meals of the future feeding system. These unitized meals will become the operational ration, replacing the present operational B ration. Table 31 compares the cost of transporting 30,000 existing B rations and equivalent quantities of the proposed unitized meals from CONUS to Southeast Asia. In spite of decreased weight, total transportation costs for unitized meals are higher than those for B rations. For the unitized meals the lesser domestic freight cost is more than offset by the higher ocean freight cost. The lighter weight of the unitized meals results from the inclusion of freeze-dehydrated items. The larger volume is due solely to unitizing, inasmuch as canned, freeze-dehydrated, and irradiated items are of equal size.

TABLE 31

COST OF TRANSPORTING B RATIONS AND UNITIZED MEALS

Type of meal	Quantity	Weight, cwt	Volume, ft^3	Cost, dollars		
				Rail	Ocean	Total
B ration[a]	30,000	1800	95	3110	2760	5870
Quick-serve, 25-man[b]	3,600 cartons	1350	131	2340	3800	6140
Quick-serve, 6-man[c]	15,000 cartons	1350	169	2340	4900	7240
Uncooked, 25-man[d]	3,600 cartons	1490	131	2580	3800	6380

[a]6 lb, 0.13 ft^3 per ration.[44]
[b]37.5 lb, 1.45 ft^3 per carton.[80]
[c]9 lb, 0.45 ft^3 per carton.[80]
[d]Assumed 10 percent heavier than 25-man quick-serve meal.

It is clear from the foregoing that, to the extent that irradiated meat replaces chilled meat, the cost of delivering food overseas will be less because of lower freight costs. The straight substitution of irradiated for the canned meat of the B ration, however, will have no effect on transportation costs, except to the extent that the development of a lighter-weight packaging material for irradiated meat may reduce total weight.

Analysis of the comparative cost of transporting the unitized rations, containing irradiated and freeze-dehydrated components, and the canned B ration is less simple. QMR for the 25- and 6-man quick-serve meals specify the maximum use of freeze-dehydrated items. When this unitized ration is developed and standardized, transportation economies may be realized if the package weight is small enough to offset any increased volume resulting from modularization. The same could be said with respect to the 25-man uncooked meal were it not of irradiated components. Because irradiated foods do not lose weight in processing, the package weight will be heavier than the corresponding quick-serve meal, and reduction in transportation costs will be correspondingly difficult to achieve.

COST COMPARISON

Thermal processing of canned meat costs from 0.8 to 5 cents/lb, and frozen food processing costs from 2 to 3.5 cents/lb. Processing costs from approximately 2 to 8 cents/lb for freeze-dehydration and from approximately 1 to 6 cents/lb for irradiation are estimated in this chapter. In terms of processing costs, therefore, both freeze-dehydration and irradiation are competitive techniques for the preservation of food. Transportation costs for freeze-dehydrated and irradiated food will be less than for fresh or frozen food. Increased costs that may result from modularization in the proposed future rations must be weighed against the logistical savings discussed in the preceding section.

PROVISION OF A MOBILIZATION BASE

This section investigates the capability to provide an adequate mobilization base of irradiated foods for the armed forces. An adequate mobilization base entails a supply of irradiated foods on hand for the unannounced day when war might erupt, plus an industrial capacity for irradiation that can supply continuing military needs. This problem involves the time required by industry to meet requirements in terms of the probable cost in money, time, and other resources. Irradiated foods will have an impact on strategic reserve concepts. The natural growth of a radiation-processing industry may have a similar impact on irradiation costs and on the ready availability of irradiated foods for emergencies.

An adequate production base is a necessary component of any mobilization base. For rations in recent years QMC had only to turn to America's commercial canneries and other food concerns. On the other hand operational and logistical requirements expected in future wars have caused QMC to direct research programs for development of processing methods for freeze-dehydrated and irradiated foods. Inasmuch as radiation processing of foods has not yet been attempted commercially, at present no irradiation production base exists that can be depended on for the establishment of a mobilization base. However, a small number of industrial organizations are already utilizing radiation to sterilize pharmaceuticals, sutures, and hospital trays and for altering polyolefin wire and chemicals.[63] An examination of processing equipment required for a production base can be made. Earlier in this study it was determined that radiation processing of meats could be most economically accomplished with machines producing electrons of beam energies below 10 mev.

Construction and operating cost estimates of irradiation equipment can be computed from data gathered from manufacturers of experimental accelerators. At least one manufacturer is building 3- to 15-kw accelerators for commercial use. Although electron accelerators are not being mass produced, machines of 45, 100, and even 1000 kw are on the drawing boards.[66,81] However, it is necessary first to establish the size of machines best suited for processing adequate quantities of food. At any given dose the output is directly proportional to the power. For comparison, outputs of low-, medium-, and high-powered accelerators were computed with the following results: a 5-kw accelerator would process 500 lb of meat per hour; a 30-kw accelerator, 3000 lb/hr; and a 100-kw accelerator, 10,000 lb/hr. A selection obviously must be made for the machine size that most economically delivers the required output. Assuming that the rate of meat consumption by combat troops is $^2/_3$ lb/man/day as found

in WWII experience,[31] a modest number of accelerators could meet this demand. On this basis Fig. 11 shows that in the event of limited war one 5-kw accelerator could process enough meat to satisfy the daily needs of approximately 14,000 men. Accelerators of 5-kw power are currently being built that could be used to establish a production base for limited war during 1965–1975 with little difficulty. Only 12 of the 30-kw accelerators would be needed to process meat for 1 million men annually. Prototypes of these accelerators are already in existence.

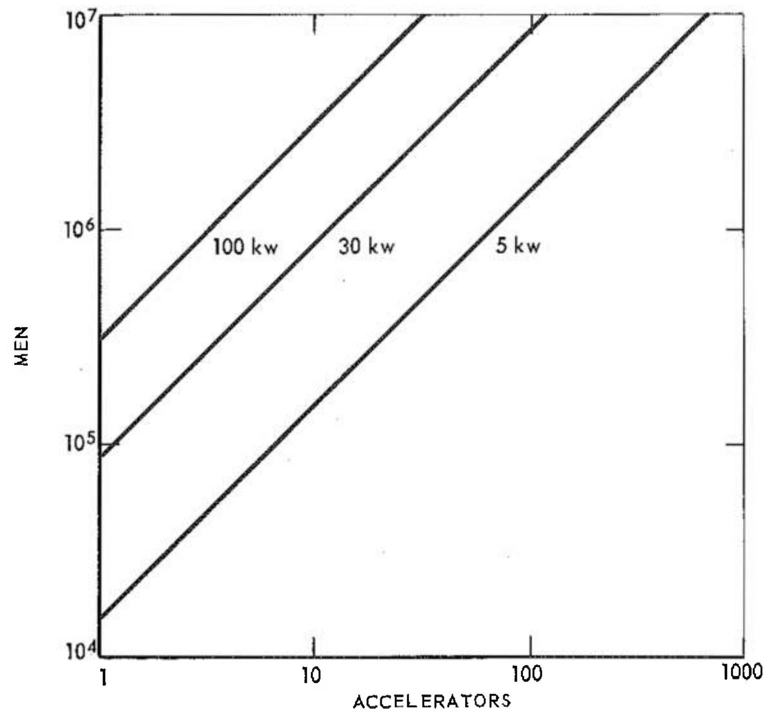

Fig. 11—Number of Accelerators Needed to Treat Meats for Armed-Forces Personnel

To meet the annual requirements of general war, possibly involving 2 million men, 7 100-kw accelerators, 24 30-kw accelerators, or 140 5-kw accelerators would be required.

If properly designed production facilities should not be available by 1965, the radiation research facility to be installed at the Quartermaster Research and Engineering Command (QMRECOMD) at Natick, Mass., could be used for production after certain modification for product flow. If emergency mobilization dictated full-time use of this facility (7000 hr/year or approximately 19 hr/day), then the daily processing rate would equal the daily meat requirement for 51,000 men. In other words this modified facility could satisfy the production-base requirement for limited war.

The electron irradiation production base could be augmented in an emergency by the utilization of gamma sources. There are many gamma-irradiation

facilities in existence today. In fact 52 facilities utilizing nearly 273,000 curies of Co^{60} are in operation, and construction of a 2-megacurie facility at the Brookhaven National Laboratories has begun.[62] Additionally a 1-megacurie Co^{60} source is to be installed at QMRECOMD at Natick. Therefore by 1965 at least 3.273 megacuries of Co^{60} should be in use, equivalent to a power output of 9.1 kw (see App B for conversion equation). Utilization of 3.273 megacuries of Co^{60} for meat irradiation would mean a production rate of 1600 lb/hr. At this rate the daily meat needs of 45,000 men could be met. Therefore if adequate production facilities were not built by 1965, the conversion of gamma and electron irradiation facilities would provide a production base that would support 96,400 men.

TABLE 32

ANNUAL CAPITAL AND OPERATING COSTS FOR MEAT PROCESSING
(In millions of dollars)

Manpower level	First year		Subsequent years[a]	
	30 kw	100 kw	30 kw	100 kw
10^4 men	0.039–0.057	0.016–0.029	0.020	0.010
10^6 men	3.9–5.7	1.6–2.9	2.0	1.0
10^7 men	39.0–57.0	16.0–29.0	20.0	10.0

[a]No amortization, operating costs only.

Estimates of yearly costs are shown in Table 32 for processing meats with 30- and 100-kw accelerators at three manpower levels in terms of total annual costs for the first year of full-scale production (7000 hr) and for subsequent years of full-scale production. The range of first-year costs is due to the spread of estimated capital costs. If no amortization costs are considered, costs in subsequent years of operation will be due only to operating and maintenance costs. It can be readily observed that the cost of higher-powered machines in terms of numbers of men fed would be most economical. Although industry is currently oriented toward low-powered low-energy accelerators for other purposes, there is no technological limitation to the use of the more economical higher-powered low-energy (less than 10-mev) accelerators for radiation sterilization of foods.

In the 1965–1975 time frame irradiated meats will actually comprise less than 100 percent of the operational requirement for meat rations. For example, QMC has estimated that a modern field army will require approximately 18 percent individual meals and 34 percent large-group meals.[31] If it is assumed that the individual combat ration will require the exclusive use of irradiated meats and that a major portion of the meat for large-group feeding will be irradiated, then irradiated meats would be used in roughly 50 percent of the meat rations. Based on these considerations the estimated cost for irradiated-meat items in field-army rations would be more nearly like those shown in Table 33.

Before discussing the requirements for attainment of an adequate strategic reserve of irradiated meats, certain observations must be made. First the process of procuring perishable subsistence (including fresh meats) currently requires a lead time of about 1 month. Second QMC usually stocks a 15-month food supply in "chilled" commercial warehouses and general military depots (12-month operational reserve plus 3-month safety reserve).[83] Third it is estimated that a 9- to 12-month lead time would be required to construct radiation facilities for processing meats.[66,81]

TABLE 33

ADJUSTED ANNUAL CAPITAL AND OPERATING COSTS OF MEAT PROCESSING PER 1 MILLION MEN

(In millions of dollars)

Year of operation	Accelerator, kw	
	30	100
First year	2.0–2.9	0.8–1.5
Subsequent years[a]	1.0	0.5

[a]No amortization, operating costs only.

On the basis of data shown in Fig. 1 the number of electron accelerators needed to process an adequate irradiated-meat reserve was determined. During 1 year of operation approximately nine 100-kw electron accelerators would be needed to process a complete 15-month meat reserve for 1 million men. If irradiated meats will be needed for only about 50 percent of the field-army meat-feeding situations, this accelerator requirement can be reduced by one-half.

The cost of setting up a production base of 100-kw accelerators to process irradiated meats for a 15-month supply is estimated to be $1.0 million to $1.8 million per 1 million men. The cost of the meat would be added to this estimate. The initial cost of the 15-month reserve, including the cost of irradiation facilities and the meat required, would total approximately $58 million per 1 million men.

In establishing an adequate production base, accelerators would be integrated into large meat-processing centers. Centralization of these operations at each facility would eliminate much of the pipeline time currently involved in getting meat to the consumer. Animals could be killed and the meat chilled, cut, packed, and irradiated at a single location. These facilities should be located in areas outside the CONUS industrial heartland because of their lower vulnerability to attack and destruction focused on the large industrial cities. Processing could be established in the major slaughterhouse cities such as Omaha, St. Louis, St. Paul, Sioux City, Kansas City, Fort Worth, Chicago, and Denver.

Part-time use (3500 hr) of the Natick, Mass., research accelerator during the 12-month period of production-base construction would provide a 3200-ton

irradiated-meat reserve, representing a 9.6-day supply for 2 million men or a 1-year supply for 60,000 men. Of course the Natick output could be augmented by the gamma facility there by using other government-owned irradiation facilities or by leasing industry-owned accelerators. The degree to which such components might influence the rate of buildup of a strategic reserve is difficult to assess and, although they could satisfy meat needs in the event of a limited war, such facilities could not augment the general-war requirement to any significant degree.

From the foregoing several conclusions may be drawn. Five-kilowatt electron accelerators, now in production, could satisfy irradiated-meat requirements for limited war and 30-kw machines, now on the drawing boards, could also meet the demand. However, to satisfy irradiated-meat needs for general war the higher-powered 100-kw accelerators would be required. If properly designed meat-irradiation facilities were not in operation by 1965, the electron accelerator at QMRECOMD, Natick, Mass., and existing Co^{60} facilities could satisfy the limited-war requirement, but a few months' lead time would be required to add production-line handling equipment. The higher-powered 100-kw accelerator would be much more economical for irradiating meats than the 30-kw accelerator.

It might require 9 to 12 months to build an adequate production base and an additional year to build up a 15-month irradiated-meat reserve for 2 million men. An outstanding feature of this reserve would be the absence of a refrigeration requirement, resulting in a reduction in storage costs, which was previously discussed.

Integrated meat-processing and -irradiation facilities could be located in the major slaughterhouse cities outside the CONUS industrial heartland and would therefore have a low vulnerability to attack and destruction aimed at the large industrial cities.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

Foods can be processed by gamma radiation from Co^{60} or by electron accelerators below energy levels of 10 mev without inducing measurable radioactivity in the foods. In order to be approved by the Food and Drug Administration for use in rations, irradiated foods must not show radioactivity levels that are distinguishable from background. Processing of meats requires an exposure dose of 4.5 Mrad preceded by heating to an internal temperature of about 160°F. Beef and pork processed in this way have remained acceptable for at least 25 months at 70°F storage temperature and for 16 months at 100°F. Bacon and ham have been stored about 1 year and chicken for about 1½ years with good acceptability. Flexible packaging is desired, but materials developed to date are not completely satisfactory to meet all military requirements.

Numerous extensive studies have been conducted to determine the wholesomeness of irradiated foods. Although analyses of the results of long-term animal feeding tests show no harmful effects attributable to radiation processing beyond correctable vitamin loss, prudently cautious recommendations by TSG include about 3 years more of research for completion of the wholesomeness study program.

The present feeding system for a field army in a theater of operations involves (a) the use of the bulk B ration prepared and served by organic mess personnel to most troops as far forward as the tactical situation will permit; (b) the use of a canned 5-in-1 ration to feed small groups whose mission or tactical situation prevents their return to their parent unit for messing; and (c) the use of the canned C ration for individuals separated from group feeding by their tactical situation.

This study shows that logistical and operational advantages would be gained in the 1965–1975 time frame by using a unitized meal system and changing the feeding concept to eliminate field kitchens and food service personnel in units requiring high mobility and dispersion of troops. If irradiated foods are available, they could provide the best single component of meals for use under most combat situations; and if freeze-dehydrated foods are also available, the latter could provide the easiest means for small groups of men to prepare a quick-serve meal. Irradiated foods have an advantage over freeze-dehydrated foods in that the latter would not be operationally suitable for the requirements of an individual ready-to-eat combat meal. The use of unitized ready-to-eat meals containing irradiated foods would be of considerable tactical advantage in the 1965–1975 time frame to ground forces in combat

situations requiring high mobility and dispersion of troops. The ready-to-eat individual combat meal, with irradiated food components in a flexible package, is urgently needed for the best ration support of Marine Corps, airborne, STRAC, and infantry units in close contact with the enemy in situations that will not permit group feeding.[1/] For similar situations and for assault phases where resupply cannot be effected for several days an individual combat food packet; such as a lightweight high-caloric-content compressed food item is urgently required.

For less active situations where small group feeding is possible, 25-man and 6-man quick-serve meals containing freeze-dehydrated foods could be used. Uncooked irradiated and uncooked dehydrated foods could be used for meals prepared by food service personnel for larger group feeding during static situations in rear areas. Foods processed by these methods would offer approximately equal logistical advantage over canned B or C rations. Except when Navy and Air Force personnel might be deployed as ground-force units, they have little tactical requirement for either irradiated or freeze-dehydrated foods.

There is a continuing requirement for improved logistical operations to support the high mobility expected of US forces in the 1965–1975 time frame. The use of irradiated foods as the major component of rations in a theater of operations during combat would allow net fuel savings of over 96,000 tons/year/2 million men, by elimination of field kitchens, bakery companies, and refrigerant compressors. Exclusive use of dehydrated foods in rations would allow slightly smaller fuel savings of about 91,000 tons/year/2 million men. When the fuel requirements of the light-truck companies needed to supply bulk fuel to kitchens, etc. are added to the other savings for irradiated food, the total savings in fuel equals about 99,000 tons/year/2 million men, or the equivalent of 4.8 tanker trips.

The dollar savings from logistical advantages of using only rations containing irradiated components (instead of thermally processed rations) in a theater of operations for 1 year is estimated to be $412 million/2 million men, or 56 cents/man/day.

Climate, terrain, and guerrilla activities influence logistical operations in limited wars. At such times the use of irradiated foods may be more advantageous than freeze-dehydrated foods because of inadequate water supplies for reconstituting dehydrated foods.

It has been estimated that the cost of thermal processing of meat is from 0.8 to 5 cents/lb, and that frozen-food processing costs from 2 to 3.5 cents/lb. The estimated freeze-dehydration processing costs of 2 to 8 cents/lb and irradiation processing costs of 1 to 6 cents/lb were compared with the first two methods to show that the processes were all economically competitive.

A mobilization base reserve of 15 months' rations containing irradiated meat components could be obtained by establishing a production base and operating for 1 year nine 100-kw electron accelerators/million men supplied. On the assumption that no more than 50 percent of the meat components of combat rations would actually be irradiated, the 1-year processing time and number of accelerators can be reduced. The research irradiation facility to be built at Natick could be pressed into emergency production by addition of production-type conveyer systems and other equipment, for the inefficient annual production of about 1 year's supply for 60,000 men.

About 2 years of total lead time would be required to establish a production base and produce the 15-month reserve supply described. The accelerators are estimated to cost a total of $1.0 million to $1.8 million/million men. The total initial cost of the 15-month reserve (irradiation facilities plus meat) would be approximately $58 million/million men.

CONCLUSIONS

1. An accelerated rate of research is necessary to complete wholesomeness studies and to overcome developmental problems relating to flexible packaging and acceptability, if irradiated meats are to be available to the armed forces for general use before the middle of the 1965–1975 time frame.

2. A ready-to-eat individual combat meal, with irradiated food components in a flexible package, is urgently needed for the best operational ration support of infantry, airborne, STRAC, and Marine Corps units.

3. The use of rations containing irradiated foods instead of B and C rations and the elimination of field kitchens in general war would result in logistical savings equivalent to 99,000 tons of fuel/year/2 million men in the theater of operations.

4. The logistical savings gained by employing only dehydrated foods instead of B and C rations would be equivalent to 91,000 tons of fuel/year/2 million men.

5. In 1965–1975 irradiated foods could have a distinctive advantage over all other types of foods in providing an operationally suitable individual combat meal that would be well received by fighting men.

6. The estimated cost of radiation processing of foods would be competitive with the costs of the thermal-canning, freezing, and freeze-dehydration processes.

7. About 2 years would be required to obtain a mobilization base composed of a 15-month reserve supply of rations with irradiated meats comprising 50 percent of the meat components. This time includes the estimated 9 to 12 months required to establish radiation facilities and the 12 months required to process the rations.

8. To process the 15-month supply of rations, five 100-kw accelerators/million men would be required at a cost of $1 million to $1.8 million.

RECOMMENDATIONS

1. The Army should accelerate its research in the irradiated foods program sufficiently to:

   a. Establish the wholesomeness and safety of radiation-sterilized meats at the earliest practicable date.

   b. Overcome developmental problems relating to packaging, storage, and acceptability of radiation-sterilized foods, especially meats, to attain a suitable component for the ready-to-eat individual combat meal early in the 1965–1975 time frame.

2. The Army should continue its research for the development of freeze-dehydrated foods to attain suitable operational quick-serve rations for small-group feeding early in the 1965–1975 time frame.

Appendix A

RADIATION SOURCES

DISCUSSION

This appendix describes some characteristics of radiation sources and discusses their relative merits.

Among the many possible types of nuclear radiations, neutrons, protons, and alpha particles may be immediately discarded as unsuitable for food irradition. Alpha particles and protons lack penetration ability, and neutrons are too penetrating and pass through food without producing sufficient ionization. High-speed electrons from β decay of radioactive nuclides usually have low penetration ability in food coupled with low specific activity of the parent nucleus.

X rays have good penetration ability but cannot be focused, bent, or scanned. This makes the source-to-product geometry inflexible so that the absorbed dose is a small fraction of the total radiation power. In addition the conversion from electrical power to X rays is a very inefficient process at low X-ray energies (less than 10 mev).[84] At higher X-ray energies this efficiency increases, but above 10 mev induced radioactivity may be produced in food.

Nuclear reactors have been proposed as a source of gamma rays for the irradiation of food. Cost estimates for single-purpose reactors indicate that other sources are more economical.[85,86] For this reason dual-purpose reactors were considered. Such reactors may produce both gamma rays and electrical power. In this way the sale of electrical power may be used to help defray the cost of food irradiation. In order to produce electrical power at a competitive rate a large reactor is required (120 kw). Although this scheme seems attractive, low-cost power is realized at a food output rate of about 50 tons/hr. This rate of production of irradiated food is entirely unnecessary. No dual-purpose reactors have been built, and such reactors require a large capital outlay.[84,87] Since the food industry consists of many small firms, this large capital outlay is particularly unattractive.

Radioactive-nuclide sources have gamma rays with energies of interest for food irradiation because they are capable of irradiating thick food items. Gamma rays, like X rays, cannot be focused, bent, or scanned, and they require extensive shielding because they emit rays in all directions. Other than source replenishment, which is required to keep source strength constant, maintenance is infrequent. However, these sources require constant monitoring for leaks.

Co^{60} is of particular interest because it is more abundant than other nuclides, it has a half life of 5.3 years and an energy level (1.1 to 1.3 mev) below that known to induce radioactivity in food, and techniques for its fabrication are known. In addition previous studies on food irradiation show that it is generally the most economical nuclide source. If the present cost of nuclide sources were decreased to 10 cents/curie (for Co^{60}), such sources would become competitive with electron accelerators.

Electron accelerators provide the most immediately applicable radiation-processing technique for food. High-speed electrons can be focused, bent, or scanned, and they induce no measurable radioactivity in food below 10 mev. Electrons, however, do not have the penetration of gamma rays. (Optimum penetration in water at 10 mev is approximately 3.3 in.)

The ability to turn electron accelerators on or off when desired without residual radiation is a definite asset. Accelerators are relatively simple to operate, require little adjustment, and have a lower shielding requirement than other sources.

Because production rate is a function of accelerator power, high-powered accelerators are desirable. At present only low-powered accelerators are available to the food processor, but high-powered machines can be constructed.

Table A1 compares some characteristics of electron accelerators and nuclide sources.

TABLE A1

COMPARISON OF ACCELERATORS AND NUCLIDE SOURCES

(For equal output rate)

Item	Accelerators	Nuclides
Penetration	Low	High
Treatment rate	High for thin layers	High for all thicknesses
Source-to-product geometry	Flexible	Inflexible
Utilization efficiency	High	Low
Shielding requirement	Low	High
Residual radioactivity	None	Some
Operation	Simple	Simple
Maintenance	Moderate	Low
Technical personnel required	Few	Moderate
Availability	High	Low
In agreement with present industrial concepts	Yes	No
Subject to AEC control	No	Yes

Appendix B

RADIATION-SOURCE CALCULATIONS

ELECTRON ACCELERATORS

In recent years accelerator development has proceeded in two major directions. First accelerators have been engineered for commercial production along with improvements in their operating reliability under industrial conditions. Second the electron energy has been increased and other techniques, such as beam splitting, have been perfected; moreover, beam power has been increased.

The electron-beam energies of particular concern for processing food are between 0.5 million and 10 mev. The range, or penetrating ability, of an electron beam is given by [84]

$$R_{max} = (0.542\ E - 0.133)/\rho \text{ for } E > 0.8 \text{ mev}$$

where R_{max} is maximum penetration in centimeters, E is electron energy in million electron volts, and ρ is density in cubic centimeters.

Total beam energy is delivered to the product within the range R_{max}, but energy deposition is not uniform at all depths. At a depth of about two-thirds R_{max} the energy deposited is equal to that deposited at the surface. This particular depth is of interest because it is the optimum thickness for uniform energy deposition.

When both sides of a product are irradiated—a technique called double bombardment—a mirror image of the penetration curve is obtained. Because the energy deposited by the beams is additive, the most useful thickness for double bombardment is about 2.4 times that obtained with single-sided irradiation[63] (see Fig. B1).

For solid materials the product can be turned over after irradiation on one side and passed through the beam a second time. Although linear speed is halved by making two passes, the product thickness is 2.4 times that used on one pass at normal speed. For liquids, beam splitting can be employed with the same increase in output.

For maximum efficiency in irradiation processing, it is necessary that the largest possible fraction of the electron-beam power be absorbed in the product and that the radiation dose be as nearly uniform throughout the product as possible. Any portion of the electron beam that does not hit the product is wasted, as is any portion of the beam that passes completely through the product. Beam power is also wasted when any part of the product receives a higher dose than necessary.

When products on a moving conveyer are passed through an electron beam the best attainable area efficiency is approximately 50 percent.[61] The reason for this is lack of uniformity in lateral intensity, which is due to an overdose received at the center of the product and the fact that a portion of the beam misses the product. This area efficiency is significantly increased to about

90 percent by scanning.[61] In scanning, the beam is rapidly deflected back and forth across the product. In practice the beam is scanned at a sufficiently high frequency so that the emerging beam has a uniform lateral distribution. The longitudinal distribution is made uniform by moving the product across the beam at a constant speed.

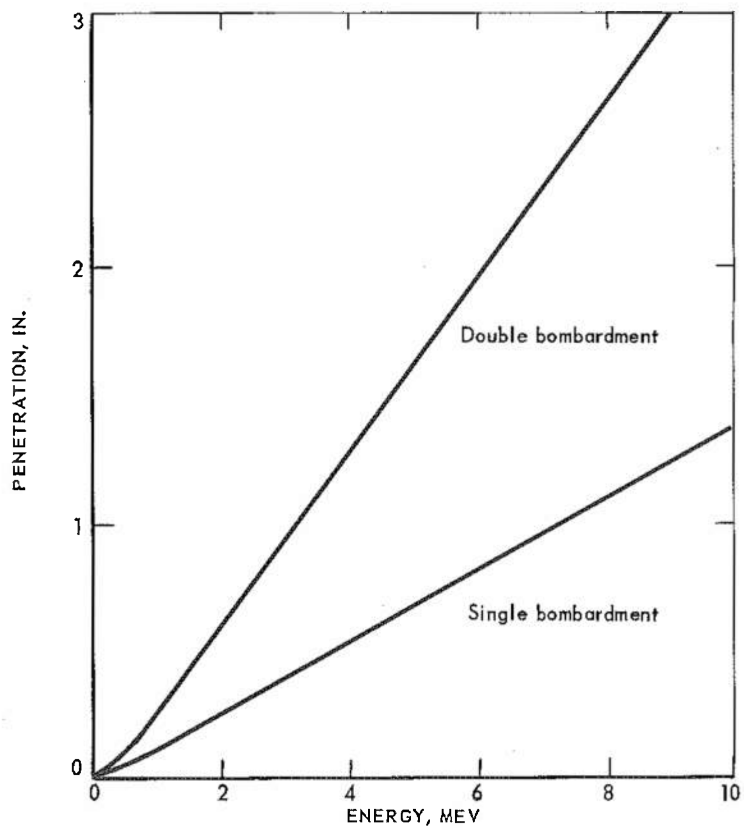

Fig. B1—Optimum Penetration for Electrons in Water

The variation of dose with depth must be taken into account in estimating thickness efficiency. This efficiency is the ratio of the cross-sectional area of the product to the total cross-sectional area. This thickness efficiency is approximately 50 percent for single-sided irradiation and approximately 70 percent for double bombardment.[61]

Beam-utilization efficiency is the product of the efficiency of area irradiation and the thickness efficiency. Table B1 shows the results of the calculations made for the various conditions discussed above.

From Table B1 it is apparent that the condition of double bombardment with scanning yields the highest beam-utilization efficiency.

For purposes of this study it is assumed that the useful irradiation-area efficiency—the ratio of product to total beam area—is 95 percent. This efficiency when multiplied by the highest beam-utilization efficiency yields an over-all efficiency factor ϵ equal to 60 percent.

TABLE B1

DETERMINATION OF BEAM-UTILIZATION EFFICIENCY

Condition	Efficiency, %		
	Area	Thickness	Beam utilization
Single-sided bombardment with stationary beam	50	50	25
Double bombardment with stationary beam	70	50	35
Single-sided bombardment with scanned beam	50	90	45
Double bombardment with scanned beam	70	90	63

CO^{60}

To facilitate comparison of Co^{60} and electron accelerators it is necessary to determine the curie strength C of any Co^{60} source and its power P in kilowatts. In order to account for self-absorption of gamma rays and to assure rated capacity at the end of a replacement period, a 10 percent energy loss is assumed in determing curie strength. The relation between curie strength and power is given by

$$C = (6.25 \times 10^{15} \times P)/(3.70 \times 10^{10} \times 0.90 \times 2.23) \text{ curies} \qquad \text{(B1)}$$

where 1 kw = 6.25×10^{25} mev/sec, 1 curie = 3.70×10^{10} disintegrations/sec, and the total disintegration energy of Co^{60} is 2.23 mev.

Food is capable of absorbing about 21 percent of the total gamma energy. This beam-utilization efficiency, combined with an area efficiency of 95 percent, yields an over-all efficiency factor ϵ equal to 20 percent. Letting P_r equal $P \times \epsilon$ and substituting this value into Eq.B1

$$C = 3.37 \times 10^{5} \times P_r \text{ curies}$$

where P_r is rated power in kilowatts.

PRODUCT OUTPUT

The theoretical product-output rate associated with any source installation can be expressed as a function of P, the source power in kilowatts, and D, the dose to the product in megarads.

$$\text{Theoretical output rate} = (P \times 10^3 \times 3600)/(D \times 10 \times 453.6)\ \text{lb/hr} \qquad \text{(B2)}$$

where 1 kw equals 1×10^3 joules/sec and 1 Mrad = 10 joules/g. The constants in Eq. B2 may be combined to give

$$\text{Theoretical output rate} = 794 \times (P/D)\ \text{lb/hr}$$

or at 4.5 Mrad

$$\text{Theoretical output rate} = 176 \times P\ \text{lb/hr}$$

An estimate of practical product-output rate (i.e., production rate) at 4.5 Mrad may be given by

$$\text{Production rate} = 176 \times P \times \epsilon\ \text{lb/hr}$$

where ϵ = the over-all efficiency.

Let $P_r = P \times \epsilon$ so that

$$\text{Production rate} = 176 \times P_r\ \text{lb/hr}$$

Table B2 shows source-power requirements for an electron accelerator and Co^{60} source as a function of production rate.

TABLE B2

RADIATION-SOURCE POWER REQUIREMENTS

Production rate, lb/hr	P_r, kw	Radiation sources: Electron accelerator E = 60%	Radiation sources: Co^{60} E = 20%
		P, kw	
1,000	5.7	9.5	28.5
2,000	11.4	19.0	57.0
3,000	17.0	28.4	85.0
6,000	34.0	56.6	170
10,000	57.0	95.0	285

PROCESSING COST

Processing cost for any radiation source may be determined by

$$\text{Processing cost} = (C_n \times 100)/(\text{production rate} \times N \times 7000)\ \text{cents/lb}$$

where C_n is cumulative cost in dollars after N years of operation and 7000 is the number of hours of operation per year.

Substituting $176 \times P_r$ for production rate and simplifying gives

$$\text{Processing cost} = (8.12 \times 10^{-5}) \times C_n/(P_r \times N)\ \text{cents/lb}$$

Appendix C

TACTICAL ASPECTS

INTRODUCTION

This appendix examines the tactical implications of introducing irradiated and/or freeze-dehydrated rations into the Army feeding system.

The examination of tactical utility of the proposed rations is restricted to units of division size and smaller. Emphasis is directed toward feeding problems of the individual soldier and the small group, from contact area through reserve and support areas to the rear boundary of the division. Consideration is given to the characteristic requirements of maneuver and service elements of the division and to the requirements of specialized units in the several arms.

Current thinking with respect to the fluidity of the future battlefield reflects universal acceptance of requirements for austerity compatible with wholesome, acceptable food. The effect of good meals on morale is well recognized, and although the need for greater battlefield mobility has increased the importance of reducing weight and volume in all classes of supplies, general officers from all arms have stated the need for serving to their troops the best possible food in every situation.[35]

Although the division requirements for class I supplies are small in comparison to the requirements for classes III and V, (6 to 8 percent vs 73 to 83 percent of total division supply for the Reorganized Current Armored Division or Reorganized Current Infantry Division in the attack),[44] the importance of food supplies to the success of a military mission is obvious. Increased mobility and dispersion of all division elements lessen the possibility of establishing fixed patterns of resupply. Existing problems are magnified, and new problems are introduced, all of which point toward the need for a simplified feeding system for troops in combat. Many situations are anticipated in which small groups or even individuals will be forced to rely, more than in past warfare, on rations that will provide them meals satisfactory for relatively long periods and that will require no skilled mess personnel for preparation.

A solution is offered by QMC in the proposed plan for simplified food logistics.[88] Designed to meet the requirements of the atomic battlefield, the system will introduce rations characterized by (a) reduced weight and volume, (b) improved packaging, (c) simplicity of preparation with a minimum of special equipment or personnel, (d) flexibility of use, (e) no refrigeration requirements, and (f) a high level of wholesomeness and troop acceptability.

METHODOLOGY

Published information pertinent to the problem was supplemented by conferences with military personnel selected for experience in the areas of interest.

The discussions were oriented to identify and rank the critical factors in future combat feeding, to indicate the needs of the unit or arm represented, and to indicate where irradiated and/or freeze-dehydrated rations would be of greatest value.

Interviews were conducted with personnel from each of the following organizations:

(a) Quartermaster Board
(b) Office of the Quartermaster General
(c) US Army Command and General Staff College, Department of Combat Developments, CGSC
(d) USCONARC: Combat Development Section and G3 Section, representatives from armor, infantry, artillery, special forces
(e) Marine Corps, Landing Force Development Activities
(f) DCSLOG, Special Forces Section
(g) Air Force
(h) Second US Army, Food Services Officer
(i) Ft George G. Meade, Post QM
(j) 35th AA Bde, Food Advisor
(k) 3d Armd Cav Regt (STRAC)

Where possible, interviews were conducted individually to provide maximum independence of expression and fullest participation by each representative. The selected personnel ranged in rank from colonel to sergeant first class, all but one of whom had combat experience, with duties ranging from regimental commander to first cook.

CRITICAL FACTORS IN COMBAT FEEDING

A consensus was evident in published data and in interviews conducted with military personnel with respect to the factors of greatest significance in combat feeding. These factors are morale; ease of preparation and time required; weight, volume, and packaging; and water. The order of importance varies with the various arms and branches and with the particular mission or pattern of activity.

Morale. Although the need for austerity in combat feeding[88] is recognized if the demands for fast, independent movement by small groups on the future battlefield are to be met, there is universal agreement that the US aim should be "hot meals" for the troops whenever possible. This goal introduces considerable controversy regarding the need for, and utilization of, mess personnel. It is obvious that the individual soldier will have to be more self-sufficient with respect to feeding than he was in any past conflict. His training will have to emphasize the acceptance of simple nourishing meals (many of which he must prepare himself) and good self-discipline in the utilization of his rations and water.[89]

An unpublished study conducted by the Quartermaster Board during 1959 visualized few situations in which small groups would not be able to assemble to prepare quick-serve meals and proposed no attached mess personnel from

the forward edge of the battle area to division rear. However, recognition of the morale value of mess personnel was apparent since the study proposed large mess facilities from division to army, from which personnel could be dispatched forward to augment division elements when sufficiently static situations occurred.[90] The study anticipated the use of quick-serve unitized meals for small groups and individual ready-to-eat meals employing freeze-dehydrated and/or irradiated rations. A more recent appraisal of the situation, however, indicates that the new items will probably not become available before 1968. A position paper prepared by TQMG proposed field kitchens at battalion level from which food would be dispatched to company messes as the situation permitted.[32]

The quality of food is also important to morale. Although still in developmental stages, irradiated foods and freeze-dehydrated foods give promise of providing food of high palatability, i.e., in "fresh-like" condition. Experienced mess personnel indicate an urgent requirement for an improved individual meal that could supply, with no effort other than a simple heating procedure, a hot meal to isolated troops to whom group messing facilities were not available. Troop commanders know by experience that the soldier is willing to use C or K rations as long as the situation or his mission requires him to do so, provided that he will be served a good hot meal by mess personnel at the earliest opportunity. With adequate developmental effort both irradiated foods and freeze-dehydrated foods can meet the requirements for better, more easily prepared individual and group meals.

Ease of Preparation and Time Required. These two factors are closely allied to morale. It is reasonable to assume that a tired soldier, offered a brief respite from his duties (especially following a period of contact with the enemy), would find the task of preparing his own meal unattractive. However, this objection is primarily applicable to the freeze-dehydrated quick-serve rations that require heating water and mixing to reconstitute the meal. Irradiated rations, on the other hand, will require no preparation other than optional heating, thus minimizing time requirements.

A study conducted at the Combat Development Experimentation Center (CDEC) to assess the tactical utility of the quick-serve ration[91] containing freeze-dehydrated foods indicated that a palatable and acceptable meal can be satisfactorily prepared by untrained troops. Designed to meet the requirements of units not actively engaged at the front line, this ration was found unsuitable with respect to speed of preparation and consumption and adaptability for use by small detached groups. During field tests with troops at Ft Ord, Calif., in the spring of 1959, it was found that the 6-in-1 and 25-in-1 meals required 70 to 90 min to prepare, consume, and clean up.[92]

Another experiment with troops at Ft Lee and Ft Eustis, Va., provided a comparison of time requirements for the current 5-in-1 field ration.[93] For this ration an average time of 56 min was required. It is apparent that unless preparation times of the quick-serve ration can be drastically reduced, the activity of troops in a highly mobile situation could be seriously impaired. Profitable developmental effort could be directed toward equipment that would permit heating water and reconstituting meals during vehicular or dismounted movement.

In the more static situations in the division area where kitchen equipment and mess personnel are available, time is less critical but is still important. About 2 hr in daylight and $2\frac{1}{2}$ hr in darkness are required to cook a hot meal, starting with a hot kitchen, and an additional 45 min to 1 hr is needed for serving.[44] Experienced mess personnel estimate that about 45 min would be required for preparation and 30 to 45 min for serving B-ration meals in darkness. This does not include other associated tasks, such as cleaning of mess gear or heating water. In combat or in exercises that simulate combat, difficulties often arise during summer months when feeding after dark and before daylight is required. In this type of situation, meals may overlap and the distribution of food and hot water for washing mess gear to scattered elements becomes difficult in the time available.

There was universal agreement among the mess personnel interviewed that rations and kitchen equipment that will permit more rapid preparation and serving of hot meals in combat are urgently needed. Until such improvements are made only a part of the potential gains from the reduced weight and higher quality of freeze-dehydrated and irradiated foods can be realized.

Weight, Volume, and Packaging. The reduction of weight and/or volume for all items of equipment and supply has long been recognized as critically important to the individual soldier. An optimum working load of 40 to 41 lb is cited;[94] this is further refined by setting 40 lb as the desirable limit for combat in wet-cold climates and 15 lb for hot climates, including weapons and ammunition.[95] Except for short-range patrol activities, the present-day American soldier may expect to enter dismounted combat with a load of ammunition and equipment ranging from about 46 to 64 lb, as shown in Table C1. This excludes his food, blanket, and any special items such as the entrenching tool, grenade-launcher attachment, or armored vest. In developing Table C1,[96] the individual-combat-meal ration that weighs 4.8 lb was used in place of the now-obsolete C ration weighing 6.5 lb. This improved ration provides a weight reduction of 26 percent, a very significant gain. However, a 3-day supply of food will still comprise nearly one-third of the rifleman's summer load and more than one-fifth of his winter burden. History has shown unexpectedly high requirements for individual use of packaged rations, and any reduction in weight or bulk is obviously very desirable. It appears unlikely that further significant reduction in ration weight can be achieved without lessening the quantity, acceptability, caloric value, or water content of the food. Obviously no reduction in the first three is tolerable, and the fourth might present difficulties in the limited special situations where water supply to individual troops is difficult.

British field testing in Kenya and Malaya, which utilized the $1\frac{3}{4}$-lb combat ration (one-man),[97] revealed no degradation in performance or morale during a 5-day exercise in hot-dry (Kenya) and hot-humid (Malaya) climates. This ration contains compressed and concentrated food items and is comparable to the US Army's 1.1-lb individual assault food packet, which is designed for use for 2 to 10 days. Riflemen in the Kenya exercise carried loads of 47 to 50 lb and in Malaya approximately 67 lb, including rations for 5 days (8.75 lb).

A British survey of medical problems of soldiers engaged in antiterrorist operations in Malaya cited the need "to produce a very much lighter ration which is still palatable enough to be used for weeks on end."[98] Four types of individual

and small-group rations were used, and in each case the weight of 1 day's food was about 4 lb. Burdens were great, and the soldiers' loads, including weapons and ammunition, ranged from 60 to 82 lb. Unpopular food items were often discarded in an effort to reduce weight. In preparation for short patrols, the men extracted a small packet from the regular 24-hr ration.

TABLE C1

INDIVIDUAL RIFLEMAN'S COMBAT LOAD[a]

Component	Weight, lb	
	Hot weather (summer, temperate)	Cold weather (winter, temperate)
Clothing	9.5	25.2
Chemical protection	6.1	8.2
Armor (helmet and liner)	3.0	3.0
Weapons		
Rifle (M14) plus 100 rd of 7.62-mm ammunition	15.7	15.7
Grenades (2)	2.6	2.6
Bayonet	0.6	0.6
Canteen (full)	2.7	2.7
Pack, personal items	5.5	5.5
Total	45.7	63.5
Ration (individual combat meal) (3)	14.4	14.4
Combined total	60.1	77.9

[a]Derived from Marshall[94] and unpublished ORO data.[96]

Supplementary data from interviews indicated that in addition to reducing the weight of the individual ration the shape of the ration container must be improved. A contoured ration package could be conveniently tucked into the field uniform and, even without a weight reduction, could be carried more comfortably.

The tactical importance of weight, volume, and packaging is not restricted to the problems of the individual soldier. More flexible patterns of surface transportation and aerial delivery for all classes of supply will be a tactical necessity on the future battlefield, with attendant requirements for maximum payload in every vehicle. Irradiated foods offer no appreciable weight reduction over current canned items, but they can provide more palatable rations with no increase in weight. Freeze-dehydrated foods offer substantially reduced weight but little if any decrease in volume, and they appear well suited for use in group messing where the weight or availability of water for reconstitution presents no problem.

Water. As in the case of the factors already discussed, ration problems associated with water are most critical to the individual and the small group to whom water supply may in some tactical situations be very difficult.

Current Army planning places water-purification units at battalion level, with bulk water transport to lower echelons a company responsibility. There are few probable theaters of war where engineer units would not be able to provide the required daily minimum of 2 gal/ man, but transportation of this water may present problems that bear heavily on desirable ration characteristics. Bulk surface transport to the company will probably be via the 250-gal semitrailer, but depending on the local situation and terrain it may have to be delivered to smaller units in 5-gal cans by truck or possibly be man-carried for short distances. It is therefore apparent that despite the 2-gal allotment at the engineer processing point, 1 to 2 qt/ day for the canteen may frequently be all that the soldier can actually have. A British study of physiological problems in tropical warfare revealed unexpectedly heavy demands for water transport and cited the canteen as "the final arbiter of what he (the soldier) can actually get to slake his thirst."[99] Observations on a battalion of African troops during a 2-month march in Nigeria[100] revealed that original planning for 2 gal/ man daily had to be revised upward to 4 gal. These observations represent hot-weather problems but indicate the possible magnitude of the water burden.

From division distribution points to company kitchens, the weight, if not the bulk, of rations to be transported can be reduced by freeze-dehydrated foods, and the availability of water appears to present no problem for company kitchens In the case of small-group feeding, however, the availability of abundant water must be assured if freeze-dehydrated items are to be employed.

A principal need for water in small- or large-group messing is the washing of mess gear and cooking utensils. Food prepared in company kitchens and sent forward in insulated containers to isolated units must be accompanied by hot water to wash and rinse individual equipment. A requirement was repeatedly stated in interviews for expendable mess gear packaged with the small-group ration or sent with the meal from the company kitchen, as well as a need for some device to facilitate rapid heating of water. These needs are indicated in the military requirements stated for the proposed family of new combat rations.[33]

Irradiated rations introduce no special requirements for water, but the use of expendable mess gear would achieve similar tactical advantages by eliminating the need for wash and rinse water.

SUMMARY

Ration and feeding-system requirements primarily depend on the pattern of activity or specific mission of the unit. Maneuver elements, frequently in a mobile or highly dispersed situation, have greater need for an improved combat-feeding system than do service elements. Despite this difference in tactical activity, this analysis revealed a consensus in both types of units with respect to the factors of greatest significance. These were (a) morale, (b) ease of preparation and time required, (c) weight, volume, and packaging, and (d) water. The interviews conducted also revealed a need for expendable mess gear to lessen

water requirements and to eliminate medical problems associated with improperly cleaned eating utensils.

Although the need for greater independence and austerity in future combat feeding was recognized, officers and enlisted men from units representing a wide spectrum of organizations and missions agreed universally on the morale value of, and continuing preference for, company-level kitchens to prepare and serve hot food whenever possible.

Radiation sterilization combined with improved packaging appears particularly well suited for use in producing lightweight, individual ready-to-eat rations and palatable nutritious "snack packets" for use on short-duration missions when a full ration is not required.

In combination with freeze-dehydration, radiation processing is applicable to (a) better quick-serve, unitized, small-group meals with shorter preparation times for use where the tactical situation permits, and (b) improved large-group-feeding-type rations of reduced weight and volume for use in more stable situations.

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